U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-259 992

Wastewater Treatment by Natural and Artificial Marshes

Wisconsin Univ -Oshkosh

Prepared for

Robert S Kerr Environmental Research Lab, Ada, Okla

Sep 76

328048

PB 259 992

EPA-600/2-76-207
September 1976

Environmental Protection Technology Series

WASTEWATER TREATMENT BY NATURAL AND ARTIFICIAL MARSHES

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-207

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE WASTEWATER TREATMENT BY NATURAL AND ARTIFICIAL MARSHES

5. REPORT DATE September 1976 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Frederic L. Spangler
William E. Sloey
C. W. Fetter, Jr.

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
University of Wisconsin-Oshkosh
Oshkosh, Wisconsin 54901

10. PROGRAM ELEMENT NO. 1BC611

11. CONTRACT/GRANT NO. R803794 and S801042

12. SPONSORING AGENCY NAME AND ADDRESS
Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

13. TYPE OF REPORT AND PERIOD COVERED Final - 6/72 - 6/76

14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Investigations were conducted on the use of artificial and natural marshes as purifiers of effluent from municipal treatment plants. Observations were made on marsh influent and effluent quality. Phosphorus distribution in the ecosystem and removal by harvesting were studied. Responses of the vegetation to repeated harvesting were recorded.

Artificial marshes consisted of plastic-lined excavations containing emergent vegetation, especially Scirpus validus, growing in gravel. Various combinations of retention time, primary effluent, secondary effluent, basin shape, and depth of planting medium were studied. A polluted natural marsh was studied simultaneously.

The degree of improvement in water quality suggests that the process may be acceptable for certain treatment applications. Harvesting was not a practical phosphorus removal technique. Marshes remove phosphorus in the growing season, but release it at other times. Development of management techniques for successful use of marshes for wastewater treatment is thought possible.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Effluents--sewage treatment Water pollution Primary biological productivity Pilot plant Marshes, phosphorus	Aquatic macrophytes Emergent vegetation Nutrient removal	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	**19. SECURITY CLASS** *(This Report)* UNCLASSIFIED	**21. NO. OF PAGES** 184
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	**22. PRICE** $7.50

☆USGPO: 1976 — 657-695/6130 Region 5-11

EPA-600/2-76-207
September 1976

WASTEWATER TREATMENT BY NATURAL AND ARTIFICIAL MARSHES

by

Frederic L. Spangler
William E. Sloey
C. W. Fetter, Jr.

University of Wisconsin - Oshkosh
Oshkosh, Wisconsin 54901

Grant Numbers R803794 and S801042

Project Officer

William R. Duffer
Wastewater Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

Investigations were conducted on the use of artificial and natural marshes as purifiers of effluent from municipal treatment plants. Observations were made on marsh influent and effluent quality. Phosphorus distribution in the ecosystem and removal by harvesting were studied. Responses of the vegetation to repeated harvesting were recorded.

Artificial marshes consisted of plastic-lined excavations containing emergent vegetation, especially *Scirpus validus*, growing in gravel. Various combinations of retention time, primary effluent, secondary effluent, basin shape, and depth of planting medium were studied. A polluted natural marsh was studied simultaneously.

The degree of improvement in water quality suggests that the process may be acceptable for certain treatment applications. Harvesting was not a practical phosphorus removal technique. Marshes remove phosphorus in the growing season, but release it at other times. Development of management techniques for successful use of marshes for wastewater treatment is thought possible.

This report was submitted in fulfillment of Grant Numbers S 801042 and R 803794 by East Central Wisconsin Regional Planning Commission and University of Wisconsin - Oshkosh under partial sponsorship of the Environmental Protection Agency. Work was completed as of June 4, 1976.

CONTENTS

Page

Abstract iii

List of Figures vi

List of Tables vii

Acknowledgments xi

Sections

I Conclusions 1

II Recommendations 8

III Introduction 9

IV Methods and Materials 15

V Physical Facilities 24

VI Substrate Selection and Propagation Experiments 31

VII Greenhouse Studies 38

VIII Experimental Basin Studies 42

IX Pilot Plant Studies 57

X Phosphorus Distribution and Removal 62

XI Brillion Marsh Studies 72

XII References Cited and Selected Bibliography 92

XIII Glossary 104

XIV Appendices

A Dye Studies 107

B Greenhouse 115

Preceding page blank

Sections Page

XIV Appendices (continued).

C Experimental Basins 121

D Pilot Plant 133

E Data Related to Phosphorus Distribution 154

F Brillion Marsh 156

FIGURES

No.		Page
1.	Pilot plant with bulrushes prior to harvest.	11
2.	Pilot plant after bulrushes have been harvested.	11
3.	Sampling device for obtaining water samples from desired depths in pilot plant.	17
4.	Schematic view of municipal treatment plant and experimental facilities. Experimental basins are numbered 1 - 10.	26
5.	Diagramatic cross-section of experimental basin (not to scale) showing relative positions of inlet and outlets.	27
6.	Diagramatic cross-section of pilot plant (not to scale) showing relative positions of inlet, outlets, and sampling tubes.	29
7.	Location of Spring Creek and Brillion Marsh drainage basin.	73
8.	Map of Brillion Marsh study area showing water sampling (△) and plant harvesting (⊡) sites.	75
9.	Available phosphorus in surface sediments in Brillion Marsh.	90

TABLES

No. Page

1. Phosphorus concentration as determined by three methods. 16

2. Greenhouse experiments on plant propagation. 33

3. Effectiveness of several species of plants in treatment of primary effluent in the greenhouse. 40

4. Summary of preliminary data on effectiveness of experimental basins for treating secondary effluent. August - October 1973. 43

5. Effectiveness of experimental basins in treatment of secondary effluent. Summer 1974. Five-hour retention. 49

6. Percent reduction in BOD, total solids, and total phosphorus. Summarized from Tables 5, 12 and Appendix C, Tables C-3 and C-4. 50

7. Effectiveness of experimental basins in treatment of secondary effluent during week prior to harvesting. Five-hour retention. 51

8. Effectiveness of experimental basins in treatment of secondary effluent during first week after harvesting. Five-hour retention. 51

9. Effectiveness of experimental basins in treatment of secondary effluent during third week after harvesting. Five-hour retention. 52

10. Effect of harvesting bulrushes on treatment efficiency. Percent reductions are summarized from Tables 7, 8, and 9. 53

11. Water balance data for experimental basins. 1975. 54

12. Effectiveness of experimental basins for treatment of primary effluent. Ten-day retention. 56

TABLES (continued)

No.		Page
13.	1975 sampling schedule for pilot plant.	57
14.	Effectiveness of the pilot plant in treating secondary effluent. Summer 1974.	58
15.	Effectiveness of pilot plant in treating secondary effluent. Effluent drawn from depth of 0.60 m. June 5 - July 17, 1975.	59
16.	Effectiveness of pilot plant in treating secondary effluent. Effluent drawn from depth of 0.15 m. July 17 - August 6, 1975.	60
17.	Effectiveness of pilot plant in treating secondary effluent after removal of partitions. Effluent drawn from depth of 0.60 m. August 6 - August 21, 1975.	61
18.	Effectiveness of pilot plant in treating primary effluent. August 21 - November 4, 1975.	61
19.	Phosphorus removal by harvesting of plant shoots from experimental basins, 1973.	64
20.	Phosphorus removal by multiple harvesting of experimental basins in 1974.	65
21.	Effect of harvesting frequency on phosphorus removal from an experimental basin.	66
22.	Distribution of phosphorus in plants and substrate in experimental basins.	67
23.	Phosphorus distribution in gravel of pilot plant after two summers.	69
24.	Distribution of phosphorus in pilot plant during 1975.	70
25.	Monthly rainfall at Brillion, Wisconsin.	77
26.	Manitowoc River runoff for water years 1974 and 1975.	78

TABLES (continued)

No.		Page
27.	Brillion sewage discharge and estimated Spring Creek runoff. June 1974 - June 1975.	79
28.	Mean values from long term studies at Stations I, II, III.	81
29.	Brillion sewage discharge and Spring Creek streamflow. August 19 - August 22, 1974.	82
30.	Plant tissue harvested from Brillion Marsh.	83
31.	Contribution of old and new shoots to harvestable biomass and phosphorus removal from Brillion Marsh.	85
32.	Concentration of phosphorus in harvested shoots from Brillion Marsh.	85
33.	Removal of phosphorus from Brillion Marsh by harvesting of plant shoots.	87

ACKNOWLEDGMENTS

Advice and assistance from Project Officer Dr. William R. Duffer of the Robert S. Kerr Environmental Research Laboratory, Environmental Protection Agency, were greatly appreciated.

Financial support was provided by the State of Wisconsin, Department of Natural Resources, to whom we are grateful. Dr. Everett Cann, Department of Natural Resources, contributed valuable counsel.

Personnel associated with the former Northeastern Wisconsin Regional Planning Commission, especially Mr. Gerald L. Paul, and the existing East Central Wisconsin Regional Planning Commission, especially Mr. Roy Willey, contributed to the project in several important ways.

Cooperation by the City of Seymour is hereby acknowledged. The City provided access to facilities and was extremely gracious in tolerating frequent presence of researchers and equipment. Mr. Orlin Bishop and Mr. Earl Grosse were particularly helpful.

Dr. William C. Boyle, University of Wisconsin-Madison, was generous in giving his time and expertise which were of great value.

Undoubtedly the greatest asset to the project was the work of Ms. Kathleen Garfinkel. Ms. Garfinkel supervised laboratory work and carried much of the responsibility for the myriad of details associated with daily operation. We are indebted to her for her service.

SECTION I

CONCLUSIONS

MAJOR CONCLUSION

Emergent vegetation has been used to treat wastewater biologically to a degree of purity which suggests that continued research could lead to widespread applicability of the process.

MINOR CONCLUSIONS

General

1. Natural and artificial marshes are more aesthetically pleasing than most conventional treatment facilities.

2. Small natural or artificial marshes could be employed to polish effluent from septic tanks of single buildings or small clusters of buildings.

3. Conventional treatment plants which discharge effluent into wetlands possibly should not be required to provide the high degree of wastewater purification required of other treatment plants as long as other beneficial uses of the wetlands are not interfered with.

4. Marshes remove phosphorus from water during some periods and release it at others thus acting as buffers which may be managed to great advantage.

5. Emergent vegetation can be used seasonally in Wisconsin for wastewater treatment in applications involving temporary high waste loads in summer.

6. Harvesting of emergent vegetation is not a potential method of removing a large portion of phosphorus entering a marsh.

Specific

Phosphorus Removal From Brillion Marsh --

1. Older plant tissue contains little or no phosphorus.

2. Approximately 0.6 g P m^{-2} can be removed by a single late season harvest.

3. Only a small portion of the phosphorus retained by a marsh system is incorporated into harvestable plant tissue.

4. Repeated harvesting of a natural *Typha* marsh removed only about 1 g P m^{-2}.

5. Plants at the downstream end of the natural marsh did not recover or retain the productivity of those at the upstream end of the marsh.

6. Harvesting greatly reduced the standing crop during mid-summer. Loss of cover could be detrimental to mammals and birds using the area.

7. There was replacement of *Typha* by *Sparganium* in at least one harvested quadrat.

8. The natural marsh was a moderately effective phosphorus removal system during the growing season, but the annual phosphorus output was about equal to the input.

9. Harvesting plants from Brillion Marsh would remove only about 6.5% of the phosphorus input.

10. Most of the phosphorus from the Brillion sewage treatment plant effluent was removed from the water in the first 100 m or so below the outfall.

11. The Spring Creek sediments immediately below the Brillion sewage treatment plant and those in a secondary stream receiving agricultural runoff contained 10 to 20 times as much phosphorus as the marsh sediments. Presumably, most of the phosphorus was precipitated or otherwise removed non-biologically in the stream channel.

Phosphorus Removal From Artificial Marshes --

1. Harvesting does not affect the quality of the effluent produced by the area on which the plants grew.

2. Older plant tissue contains little or no phosphorus.

3. Repeated harvesting of Scirpus during the growing season can result in the removal of 3.5 g P m^{-2}.

4. Only a small portion of the phosphorus retained by a marsh system is incorporated into harvestable plant tissue.

5. The artificial marshes retained 20 or more g P m^{-2} of which up to 80% is associated with the microflora - substrate regime.

6. Most of the phosphorus associated with the microflora - substrate regime is lost from the system over winter.

7. Harvesting reduced the total productivity (standing crop) in artificial systems, but to a lesser extent than in a natural marsh.

Water Quality Improvement In Brillion Marsh --

1. Spring Creek above the Brillion sewage treatment plant receives a variable loading of pollutants from industrial sources.

2. The effluent from the Brillion sewage treatment plant has, in general, high concentrations of BOD, COD, orthophosphate, total phosphorus and coliform bacteria.

3. During periods of low flow, as much as one-fourth to one-third of the total flow of Spring Creek where it enters Brillion Marsh is sewage treatment plant effluent.

4. During periods of low flow of Spring Creek the concentrations of BOD, COD, orthophosphate, total phosphate and coliform bacteria tend to be higher at Station II than at other times.

5. The average concentrations of BOD, COD, orthophosphate, total phosphorus and coliform bacteria were greater in Spring Creek below the sewage treatment plant than above.

6. The average value of conductivity, turbidity, nitrate, and total, suspended, and dissolved solids in Spring Creek were greater above the sewage treatment plant than below.

7. The average concentrations of BOD, COD, turbidity, nitrate, coliform bacteria, and suspended solids in Spring Creek were reduced by 29% or more by passage through some 1,900 m of Brillion Marsh from Station II to Station III.

8. The average concentrations of orthophosphate, total phosphorus, conductivity and total solids were reduced by 13% or less by passage through some 1,900 m of Brillion Marsh from Station II to Station III.

9. The observed reduction of orthophosphate, total phosphorus, conductivity and total solids could be primarily due to dilution from other, non-polluted waters entering Brillion Marsh.

10. Some of the observed reduction in the value of BOD, COD, turbidity, nitrate, coliform bacteria, and suspended solids is due to physical, chemical, and biological reactions in the marsh. Dilution also accounted for some of the observed reductions.

11. The concentration of phosphorus in the water draining from the marsh does not seem to follow any discernible pattern related to either temperature, rainfall, or season. It ranged from a low of 0.43 mg l^{-1} in September to a high of 11.85 mg l^{-1} in July.

12. The concentration of phosphorus in Spring Creek above the wastewater treatment plant follows a pattern. The higher values (1.14 to 3.61 mg P l^{-1}) occurred in October and November, when fall frosts were occurring. The values were lowest (0.03 to 0.08 mg P l^{-1}) in the winter months of December through March. Late spring, summer, and early fall values are intermediate. One very high reading (12.76 mg P l^{-1}) of July 29, 1975 seems to be an anomaly, possibly due to a slug of contaminant.

13. A special intensive study showed the concentrations of the following constituents tended to be highly variable above the marsh but relatively steady below the marsh: suspended solids, total solids, BOD, nitrate, coliform bacteria, ammonia, and total phosphorus.

14. During the special intensive study, significant reduction in concentration of the following parameters were noted: nitrate, ammonia, coliform bacteria, total phosphorus, BOD, and suspended solids.

15. A mass balance study of total phosphorus, using estimated streamflow data and average phosphorus concentrations, shows the same order of magnitude of phosphorus leaving the marsh as entering it.

Water Quality In Artificial Marshes --

1. Evapotranspiration may remove a significant fraction of the wastewater (45%) from the system, thus, strongly influencing concentrations.

2. Scirpus validus, softstem bulrush, was the best species of those

tested for use in artificial marshes. This choice was made primarily because of the favorable response to harvesting. Since harvesting is not a good method of phosphorus removal, perhaps other species may prove to be more desirable because of other characteristics.

3. Phosphorus removal of over 80% should be attainable since 84% was attained in the greenhouse and 64% was attained under less than optimum field conditions for a wastewater that was very high in total phosphorus.

4. BOD removal of well over 90% should be attainable since over 90% was attained with field conditions that could only be poorly controlled.

5. Retention time of 5 - 10 days may be required although some studies using 5-hour retention time gave quite good results except for phosphorus removal and 16-hour retention time gave nearly as good results as 10-day retention in some cases.

6. Effluent quality is not influenced by harvesting the plant shoots.

7. The artificial marsh behaved in the same manner as Brillion Marsh with regard to phosphorus removal and responses of vegetation to harvesting and other treatments.

8. In plastic-lined systems the substrate, whether gravel or soil, should be probably only about 15 cm deep and wastewater should flow through it, not over it.

9. Percent reductions for most parameters were not greatly different when primary effluent was treated than when secondary effluent was treated.

10. Special intensive studies showed the marsh system effluent to be quite constant in quality over a 24 hour period.

SECTION II

RECOMMENDATIONS

1. Nutrient cycles should be studied extensively in marshes so that management techniques can be applied effectively.

2. Artificial marshes which are lined should be designed with a shallow (15 cm) substrate and wastewater should flow through the substrate rather than over it. Unlined systems using soil instead of gravel should be tested.

3. Artificial marshes should take the form of trenches of considerable length.

4. A method should be sought for controlling the fate of phosphorus which is flushed out of a marsh after killing frosts in autumn.

5. Research should be done on the possibility that vigor of emergent vegetation is lessened by lack of some limiting factor in both natural and artificial marshes.

SECTION III

INTRODUCTION

GOALS

The concept of using marshes for waste treatment or for polishing treated wastewater is an obvious outcome of the need for new, inexpensive technology. Application of the concept has been tested in Europe with varying degrees of success. The project reported on here, from June 1972, to June 1976, had the goal of showing that wastewater passed over and/or through masses of emergent vegetation would be improved in quality biologically and chemically. It was anticipated that nutrient removal could be affected by periodic harvesting of the upper portions of the plants (Figures 1 and 2). Secondary goals were to discover the effects of varying several parameters including water depth, retention time or loading rate, nature of wastewater applied (primary or secondary effluent) and frequency of harvesting of the vegetation on quality of effluent produced.

APPLICABILITY IN WISCONSIN CLIMATE

Wetlands are widely distributed in Wisconsin and would be readily available at comparatively low cost to a significant number of users. Application of the method would have to be seasonal for climate reasons, but a number of seasonal needs exist.

Reproduced from
best available copy.

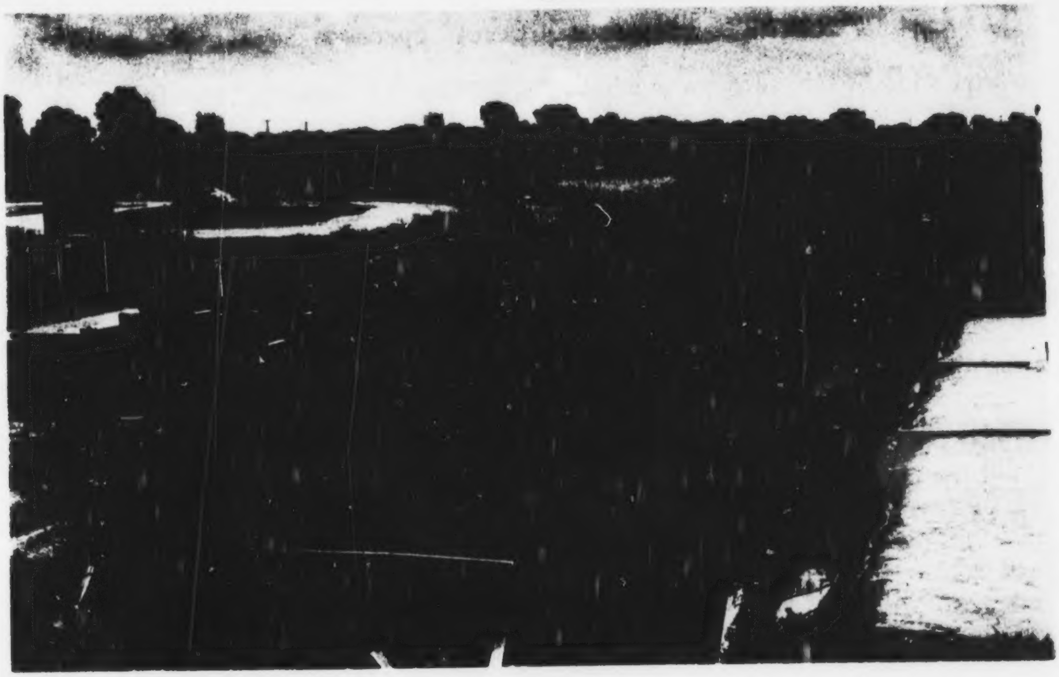


Figure 1. Pilot Plant With Bulrushes Prior to Harvest.

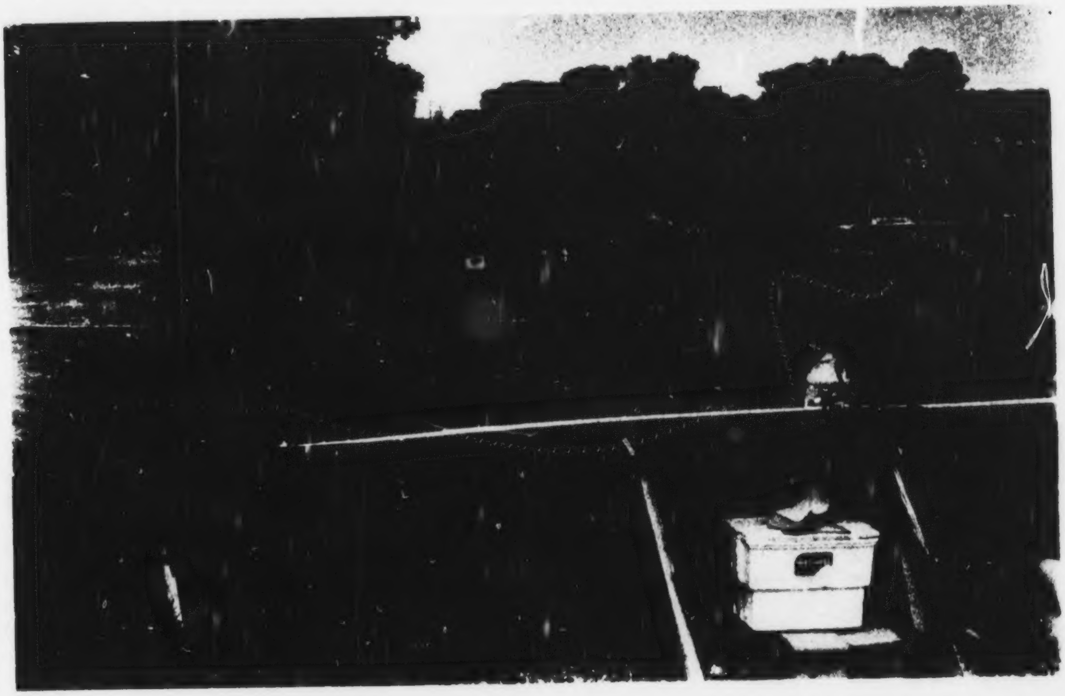


Figure 2. Pilot Plant After Bulrushes Have Been Harvested.

Needs include treatment of wastes produced by campgrounds, resort communities (with temporary high populations in summer), canning companies, agriculture, summer recreation camps, and trailer parks among others.

APPROACH

Experimental Basins and Pilot Plant

The approach used in this project involved use of plastic lined excavations in which vegetation was planted. Observations were also made on a natural marsh receiving water polluted by the outfall from a municipal treatment plant. Excavations were of two sizes. Small square ones (constructed in late summer, 1972) are referred to in this report as experimental basins. There was one large excavation, in the form of a trench, which is referred to as the pilot plant. Water depth in all excavations was controllable from zero to one meter. Flows into and out of the excavations were metered. Retention time could be varied by changing water depth and inflow rate. Analyses were performed one or more times per week on grab samples of influent and effluent. In some studies (1974 and 1975), samples were collected as frequently as every four hours for three to four days in order to discover short term temporal variation. In the later parts of the project a composite sampler was used for some sampling. Specimens of plant tissue were analyzed for phosphorus content, and cores were taken from the substrate for the purpose of studying nutrient distribution in the system.

Culture Techniques and Greenhouse Studies

Prior to field studies (summer 1972), some work was done on techniques for obtaining a number of kinds of vegetation from the natural habitat and propagating them in the study area. Also, some greenhouse observations were made (1972, 1973) in order to narrow the choice of species to be used in field applications. Following culture techniques and greenhouse experiments, field work using the experimental basins was begun (summer 1973).

In early field studies two kinds of planting media were tried. In some cases vegetation was rooted in gravel and in others it was tied to a hardware cloth on moveable frames. The frames offered the advantage of flexibility of experimental design but were abandoned because plants did not grow well on them and lodged easily. Accumulation of solids did not occur and, thus, moveable frames were not necessary for the purpose of flushing away solids.

Natural Marsh Study

Concurrent with the artificial marsh work in 1974 and 1975, observations were carried out on the Brillion Marsh with the idea of eventually deciding whether using existing natural marshes or constructing artificial ones would be the most appropriate (Section XI).

CALENDAR

Four full summer growing seasons (1972-1975) were consumed by the project. In 1972 the study site was readied for work. The summer of

1973 was consumed by preliminary sampling and was regarded largely as a period of establishment of vegetative communities in the plastic-lined excavations. Probably a longer start-up time should be used but the summers of 1974 and 1975 were regarded as producing data typical of established artificial marsh communities.

SECTION IV

METHODS AND MATERIALS

CHEMICAL AND MICROBIOLOGICAL WATER QUALITY

In all cases U.S. Environmental Protection Agency methods were followed (EPA, 1971) where applicable. Standard Methods (APHA, 1971) was also used. Samples collected at the field sites (Sections V and XI) were transported in ice chests to the laboratory where they were analyzed within 24 hours. A walk-in refrigerator was used for short-term storage as needed.

Coliform (total) densities were determined using the membrane filter procedure described by APHA (1971). The stannous chloride method was used for orthophosphate phosphorus and persulfate digestion was used to obtain total phosphorus. One experiment comparing the results of the persulfate digestion with results of the sulfuric acid - nitric acid digestion gave considerably higher results for the latter, more rigorous digestion (Table 1). The more rigorous digestion, however, was not routinely used because of the hazardous nature. Analyses of sediments and plant tissues are discussed below. The biochemical oxygen demand (BOD) test used the standard five-day incubation period.

Suction Sampling Device

In order to withdraw samples of water from known, discrete depths in the pilot plant, pipes of various lengths were permanently inserted into

Table 1. PHOSPHORUS CONCENTRATION AS DETERMINED BY THREE METHODS[a] (mg l^{-1})

	Sampling Location		
Method	Influent to Ponds	Effluent Bed 1	Effluent Bed 5
$SnCl_2$ (Orthophosphate)	34.78	23.17	22.19
Persulfate (Total Phosphorus)	48.51	23.37	21.84
H_2SO_4-HNO_3 (Total Phosphorus)	60.21	24.41	24.57

[a] APHA, Standard Methods, 13th ed. 1971.

the gravel. Water was withdrawn from them with the suction sampling device shown in Figure 3. The apparatus was rinsed with alcohol prior to collection of samples for microbiological analyses.

Analysis of Data

Direct comparison of concentrations of a material in the influent and effluent of experimental basins or pilot plant leads to erroneous conclusions about treatment efficiency. A significant fraction of the water flowing through a basin is lost from the system by evapotranspiration thus resulting in a tendency toward increasing the concentration of a material rather than decreasing it. To combat this problem we have avoided comparing concentrations as a means of judging results in most instances. Instead, we have compared the number of grams of a substance entering a basin via the influent to the number of grams leaving via the effluent. The difference is the number of grams removed by the system and can be expressed as a percent reduction as follows:

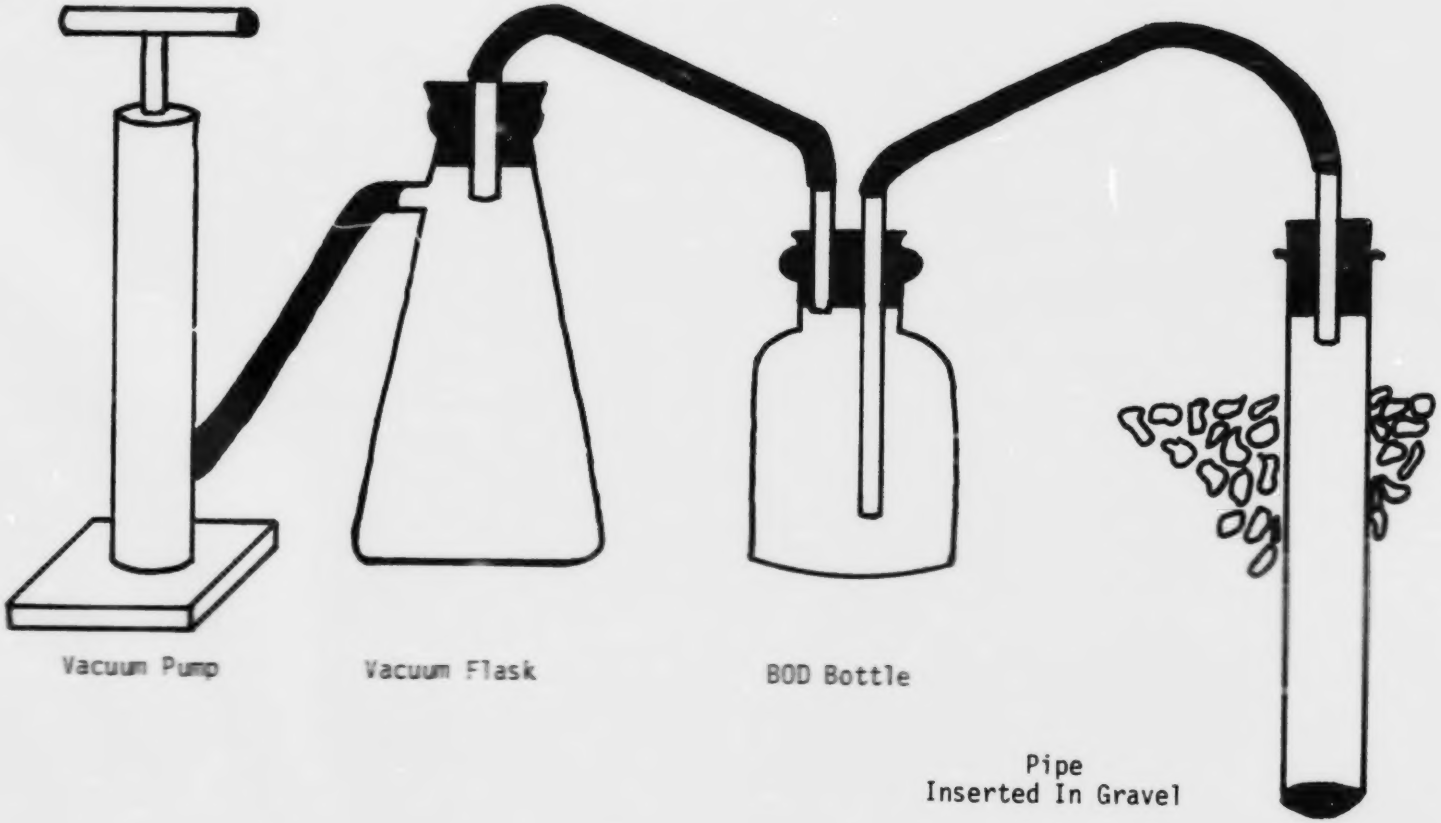


Figure 3. Sampling Device for Obtaining Water Samples from Desired Depths in Pilot Plant.

$$\text{percent reduction} = 100 \times \frac{\text{grams in} - \text{grams out}}{\text{grams in}}$$

Known volumes of influent and effluent were multiplied by mean concentrations of a material to obtain values for grams in and grams out. For other kinds of data (*i.e.* biomass, flow rates, *etc.*) no special techniques are required.

LIVING MATERIALS

Experiments on propagation techniques and on substrate suitability are described in Section VI. Actual handling of living materials was as follows. During construction of the experimental basins, rhizomes of *Scirpus acutus* and *S. validus* and tubers of *S. fluviatilis* were obtained locally and spread on the university campus lawn. They were covered with severed tops and kept moist until new shoots developed. The plants were then transplanted into the experimental basins. *Iris* were collected and placed directly into the experimental basins after excising about half of the leaf material to reduce transpiration and induce formation of new shoots.

Planting was done in September 1972. Half of the plants of each species were tied onto the wire-covered frames in four of the basins. The other half were planted in pea gravel in four basins. The two remaining basins served as controls (Figure 4):

Basin #1 - control, no plants.

Basin #3 - Softstem bulrush, 540 rhizome sections having 4-5 shoots per clump.

Basin #5 - Hardstem bulrush, 150 root clumps having new shoots.

Basin #7 - River bulrush, 540 10-14 in tall sprouts already beginning to become chlorotic; condition marginal.

Basin #9 - Iris, 540 roots, each having a sheath of 4-10 healthy new leaves.

The remainder of the plants were tied on the wire racks with nylon cord as follows:

Basin #2 - control, no plants.

Basin #4 - River bulrush, 1024 tubers with chlorotic shoots.

Basin #6 - Hardstem bulrush, 480 root clumps having new shoots.

Basin #8 - Softstem bulrush, 480 rhizomes sections having new shoots.

Basin #10 - Iris, 540 roots, each having 4-10 new leaves.

In an attempt to ward off damage by early frost the basins were covered with polyethylene supported by wood ridge poles. The transparent covers had the effect of raising the temperature by several degrees. Floods then inundated the basins on September 29, severely damaging the basins and uprooting many of the plants. The plants were re-set and some data taken, but it was obvious that little could be accomplished before winter. Inasmuch as the plants were not yet established and had little opportunity to store adequate reserves for over-wintering, we decided (November 10) to transplant the Iris, softstem, and hardstem from the pea gravel to the greenhouse to maintain them until spring. The river bulrush appeared to be dead, and all plants were left in the pond. The materials on racks were moved into basins that still held water and were covered with one foot of water until spring.

PHOSPHORUS DISTRIBUTION AND REMOVAL BY HARVESTING

Plant Harvesting Techniques and Laboratory Analyses

For the purposes of nutrient removal, the emergent plant shoots were harvested from each of the basins and Brillion Marsh by cutting with a hand sickle at about 20 cm above the substrate surface (above the intercalary meristem). The samples were placed into pre-weighed plastic bags and sealed. Fresh weight was measured in the laboratory. Then 100 g of intact shoots were cut into small sections, dried at 60 C, ground in a Wiley Mill over a #20 mesh screen and stored. Aliquots of ground tissue were analyzed for dry weight, organic weight, and phosphorus content (AOAC, 1960).

Plant Harvesting Quadrat Selection and Sizes

Experimental Basins --

Quadrats were selected for harvesting by tossing a golf ball over the shoulder. The point of impact became the NE corner of a 0.093 m^2 (1 ft^2) quadrat. The entire basin was harvested and aliquots taken for analyses at the end of the growing season and when standing crops were very small.

Pilot Plant --

Quadrats were selected as for the experimental basins, but 1 m^2 samples were taken. Three quadrats were harvested from each of the three sections of the pilot plant.

Natural (Brillion) Marsh --

Two permanent 1 m^2 quadrats were established in typical vegetation near the stream at each end of the marsh (Figure 8, Quadrats 1-4). At the upriver end of the marsh, both quadrats were located in nearly unispecific stands of Typha. At the downstream end of the marsh, there was a 15 - 30 m band of Sparganium adjacent to the stream and a wide expanse of Typha extending laterally. One quadrat was established in the Sparganium and the other in Typha. These quadrats were harvested at various intervals during the growing season and were referred to as experimental quadrats. At the end of each growing season in 1974, and 1975, a similar quadrat, referred to as a control quadrat, was harvested near each experimental quadrat.

Substrate Core Sampling Techniques and Methods of Analyses

Experimental Basins --

The golf-ball-over-the-shoulder technique was also used in locating the sites for coring. The point of impact became the center of a 12.8 cm (5 in) diameter core taken through the gravel to the plastic liner. The coring device was a two pound coffee can with both ends removed. The fibrous plant rhizomes were severed by slicing carefully around the perimeter of the device with a round-ended kitchen knife with a serrated edge. The coffee can was inserted until it came firmly in contact with the plastic liner, then the contents were carefully removed by hand. Before removing the sampler, a volume of fresh pea gravel equal to that removed was placed in the core hole. Three cores were taken from each basin on each sampling date.

Pilot Plant --

Several coring devices were designed and tested, but all either failed to recover the large sized gravel, or were so designed as to cause concern that the plastic liner in the basin would be ruptured. After all the experiments were terminated (December 5, 1975), three 15 cm deep cores were taken with the coffee can from each section in the same fashion as for the experimental basins. These samples included all of the unharvested shoots and the rhizomes and about 75% of the roots. Then, a single excavation was made in the center of each section and a 15 cm core taken in the middle of the 30-60 cm depth. The latter sample was used to represent both the 30-45 and the 45-60 cm interval.

Natural (Brillion) Marsh --

Cores were taken of the organic sediments available to the plants (uppermost 45 cm) with a 3.5 cm piston type coring device on August 5, 1975. Cores were taken in midstream at each of the water sampling stations (Figure 8), in each of the plant harvesting quadrats, in midstream just above the entrance of the channel from the Brillion sewage treatment plant, from the channel immediately below the 50 m below the sewage treatment plant, and from a secondary influent stream (Deer Creek Run) which receives runoff from a golf course and farmlands. The cores were stored frozen in their plastic core-liner tubes until analysis. Where the cores were more than 15 cm long, aliquots from the top, middle, and bottom, of each core were analyzed. If less than 15 cm of organic sediments were present, replicate cores were taken and a single aliquot analyzed from each. Only available phosphorus was determined. The extraction method was that of Olsen and Dean (1965); and the analytical methods for orthophosphate was the stannous chloride method of APHA (1971).

For the cores from both the experimental basins and the pilot plant, the plant roots and rhizomes were carefully separated from the gravel and other materials by hand. The gravel was then repeatedly washed with small volumes of distilled water until a total of 2 liters of eluate were collected. Eluate was then analyzed for dry matter, organic content and total phosphorus according to APHA (1971).

SECTION V

PHYSICAL FACILITIES

Field work was conducted on private property adjacent to the municipal treatment plant at Seymour, Wisconsin (population 2,257, Outagamie County). This site is 41 miles from the University of Wisconsin-Oshkosh campus where laboratory analyses were performed. Major features of the field facility were plastic-lined excavations in which vegetation was planted. These excavations were regarded as artificial marshes though no attempt was made to simulate natural marsh conditions. Design of the facility was done by a professional engineering firm. Construction was done in 1972 by a contractor after competitive bidding.

During operation, wastewater (primary or secondary effluent) was withdrawn at the municipal treatment plant and fed to the experimental basins after passing through a screen (in a 55 gallon drum) and an additional settling basin (modified stock tank, Figure 4). The screen and settling basin were not part of the original design, but were added later in 1973 in an attempt to alleviate some clogging problems associated with obtaining uniform flow. In 1973, the constant head tank was used to provide gravity flow to the basins. Uniform flow could not be sustained so, in 1974, the constant head tank was bypassed and a pump provided pressure. Meters were installed on feedlines and effluent pipes in all basins. Wastewater from basins was collected in a common wet-well and pumped back to the municipal treatment plant to complete the pathway.

Basins were lined with black 20 mil PVC plastic to prevent water loss to the soil. They had flat, square bottoms (9.29 m^2), sides with 2 to 1 slope, and vertical ends. A separate inlet pipe from the feedline entered each basin. Flow rates into the basins were adjusted by manually opening and closing the valves. Adjustments of flow rates and depth were the means of altering retention time. Effluent pipes were placed at depths of 15 cm, 45 cm, and 60 cm so that lower ones could be capped in order to increase water depth (Figure 5). When water depth of 0.5 m was desired it was achieved by using the bottom (6 cm) effluent pipe with a vertical standpipe attached to it. Thus, withdrawal was from the gravel instead of the surface.

In the first phase of experimental work (1973) ten basins were used. The arrangement in two rows of five basins each (Figure 4) was not experimentally significant but was a functional convenience. Pea gravel was placed to a depth of 15 cm in the bottom of each off-numbered basin to serve as a medium for roots to penetrate. Frames covered with hardware cloth were placed in even-numbered basins for the attachment of plants.

At the beginning of 1974, the use of wire-covered frames was abandoned and the even numbered basins (Figure 4) were consolidated into a single, long trench by removing partitions between them and installing a new

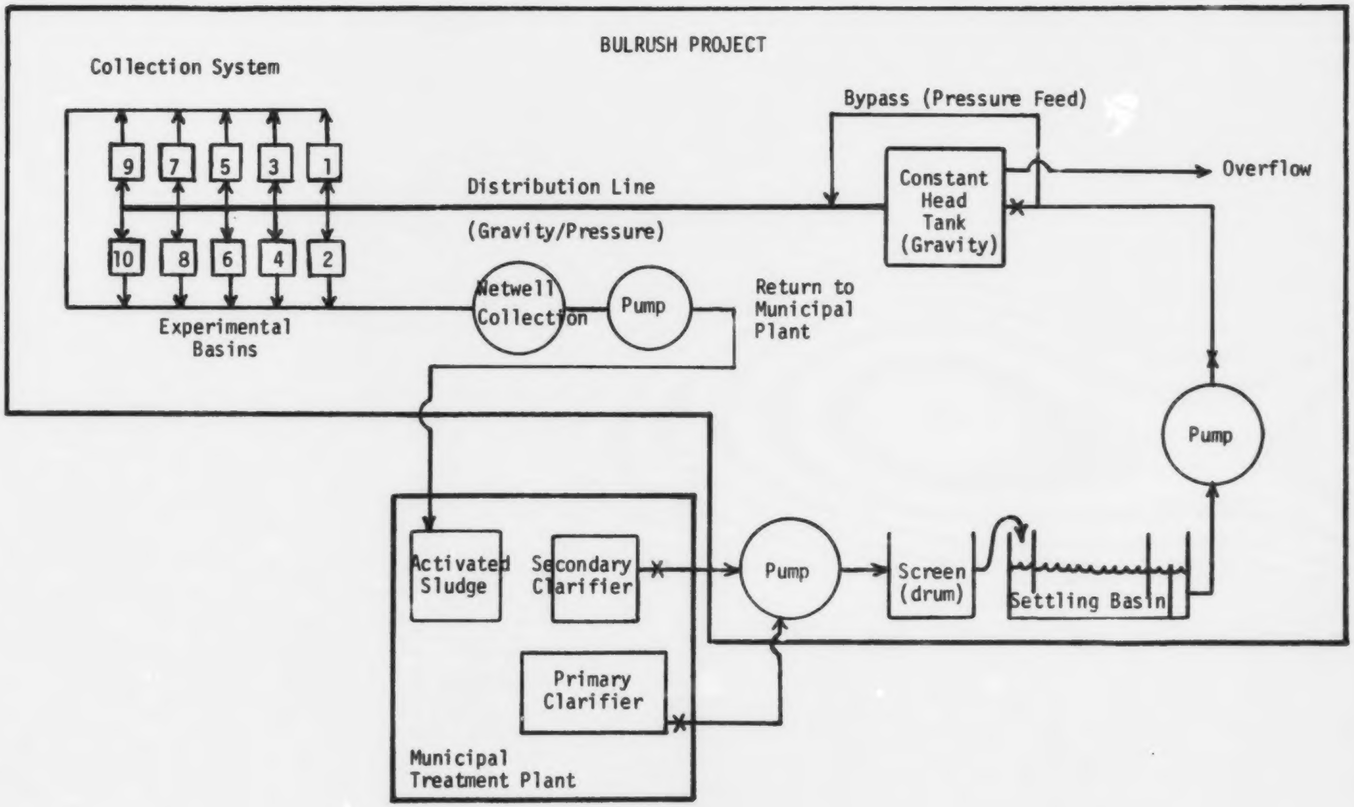


Figure 4. Schematic View of Municipal Treatment Plant and Experimental Facilities. Experimental Basins are Numbered 1 - 10.

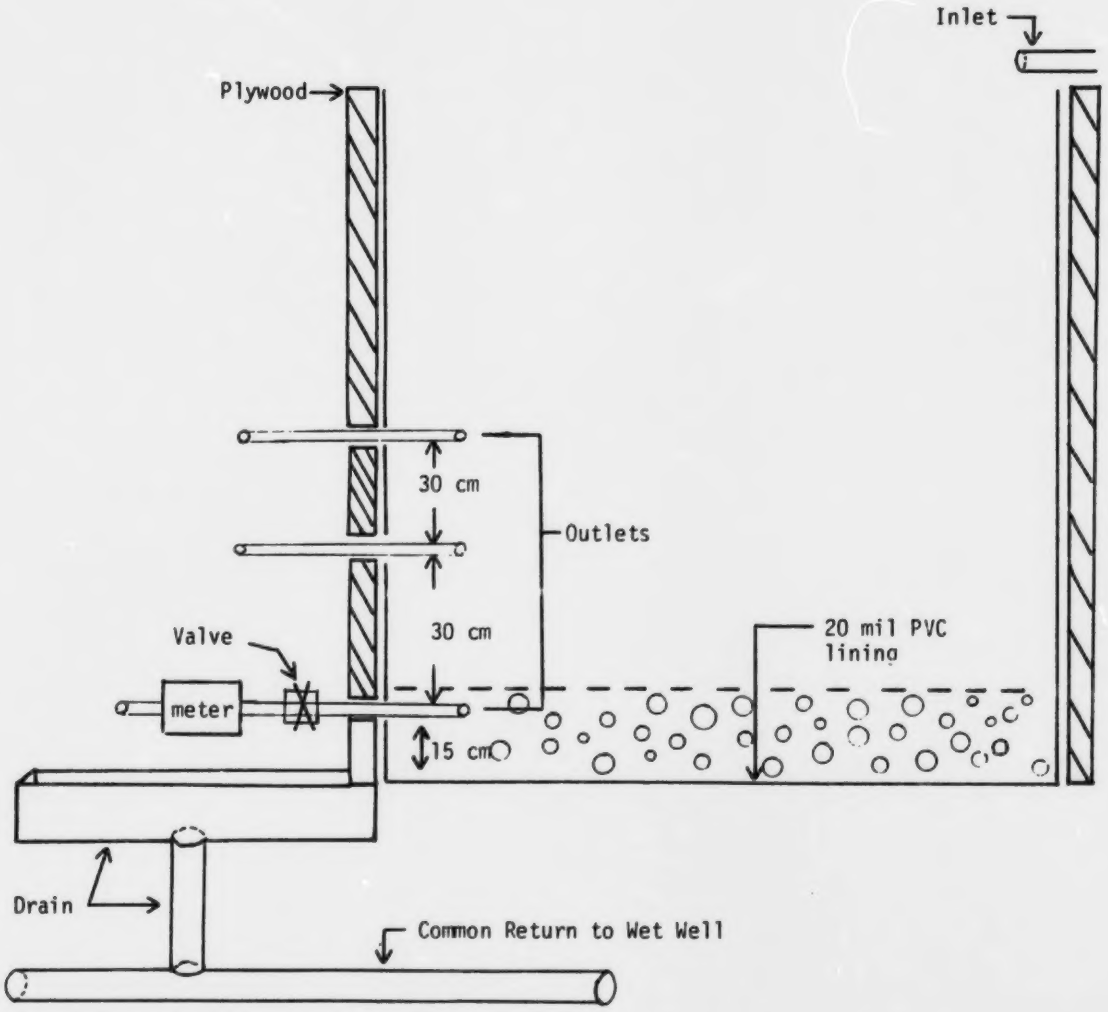


Figure 5. Diagramatic Cross Section of Experimental Basin (not to scale) Showing Relative Positions of Inlet and Outlets.

lining. This trench, the pilot plant, was 19.3 m long, 3.05 m wide at the bottom and 5.8 m wide at the top. Sides had a 2 to 1 slope as in experimental basins. A 15 cm layer of sand was put down on the bottom followed by 30 cm of coarse gravel (1.9 - 2.5 cm) then by 30 cm of pea gravel. Two baffles divided the pilot plant into three sections of equal length (Figure 6).

Influent entered the pilot plant via three pipes spaced uniformly across one end. Each pipe was a branch of a metered feedline and had a valve for flow regulation. In order to sample water at 15, 30, 45, and 60 cm, pipes of appropriate length were driven into the gravel (Figure 6) in each of the three longitudinal sections. Effluent was sampled at metered outlets in the wall at the downstream end. A four-inch drain tile line was placed across the downstream end at the bottom layer of coarse gravel. A one-inch pipe passed from the drain tile out of the pilot plant, through a flow meter to the drain. Outlets at other depths did not carry water from drain tiles. A metered overflow was provided to take off the extra water during rainstorms.

Three Rhodamine-B dye studies were conducted (July 13, July 21, and August 12, 1975) to observe hydrologic characteristics of the pilot plant. In each case, dye solution was added at the influent and samples for fluorometric readings were taken in horizontal and vertical series. In the first study, dye appeared in the effluent after 10 hours indicating surface flow. Low readings were observed at depths

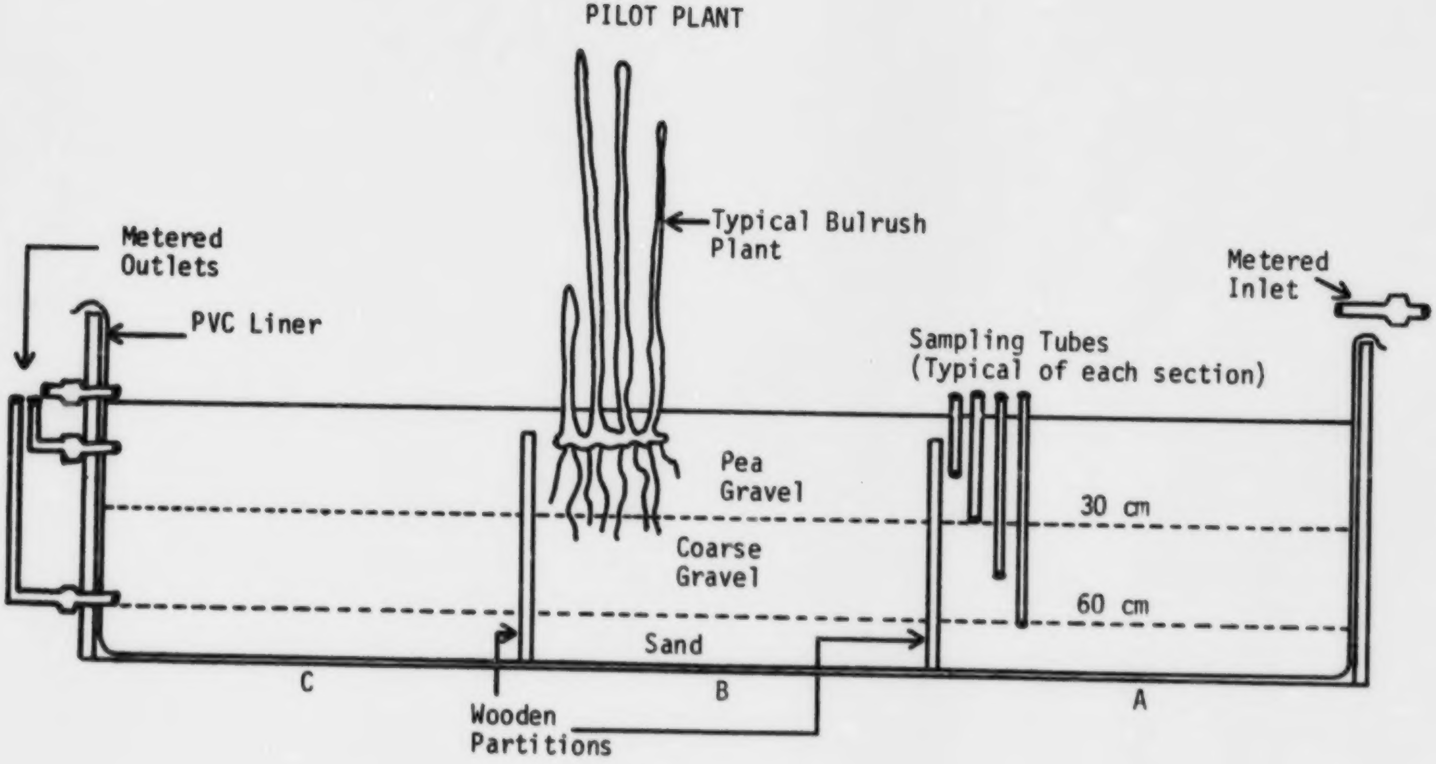


Figure 6. Diagramatic Cross-section of Pilot Plant (not to scale) Showing Relative Positions of Inlet, Outlets, and Sampling Tubes.

of 30 and 45 cm (Appendix A, Figure A-1). Prior to the second study the water level was lowered by about 2.5 cm so that no surface flow occurred. The second study indicated low flow rate in the pea gravel (zero reading at 15 cm). Dispersion into the coarse gravel was quite uniform horizontally and variable but without a distinct pattern vertically (Appendix A, Figure A-2). In spite of the uniform dispersion no dye was actually observed in the effluent. The uniform dye dispersion could not be reconciled with the distinct chemical stratification indicated by very high conductivity at 60 cm. Thus, the partitions (Figure 6) were removed to attempt to prevent stagnation. After removal of the partitions another Rhodamine-B study, this time with double the amount of dye, was done. Results were the same as in the second study. Failure to observe dye in the effluent (Appendix A, Figure A-3) could possibly be attributed to adsorption. Removal of the partitions produced a long-term improvement in the conductivity stratification but no change in dye distribution.

SECTION VI

SUBSTRATE SELECTION AND PROPAGATION EXPERIMENTS

A series of studies was undertaken at the beginning of the project in order to learn how to vegetatively propagate native plants which were likely to be useable for biological waste treatment. Criteria used in selection of species for experimental work included: 1. local availability; 2. ease of vegetative propagation; 3. rate of regrowth after harvesting; 4. tolerance to repeated harvesting. Literature reports on some native species were available. Importance of criteria 1 and 2 above is apparent. Response to harvesting was regarded as important because of the idea that nutrient removal could be achieved by repeated harvesting. Forty-two different experiments involving 1,254 individual propagules were conducted using the following species: Typha latifolia L. (cattail); Sparganium eurycarpum Engelm. (mace reed or burr reed); Phragmites australis (Cav.) Steudal (reed grass); Scirpus fluviatilis (Torr.) Gray, (river or three-square bulrush); Scirpus acutus Muhl., (hardstem bulrush); Scirpus validus Vahl. (softstem bulrush); Iris versicolor L. (wild iris). Since the most desirable kind of planting medium or substrate was not known, several kinds were tried (Table 2) in combination with varying moisture conditions. The goals of the experiments were to learn how to propagate the plants and to choose a substrate for use in the later phase of the work. Response to harvesting was determined from literature or previous experience as well as by observation.

It was determined that greatest success in propagation was realized when propagules were planted with shoots exposed to the atmosphere. Complete immersion of propagules in water inhibits new shoot development. Special treatment such as gibberellin or scarification of tubers was not effective.

The conclusion regarding choice of substrate was that it should be porous. Pea gravel was chosen for use in later work. The basis for the choice was that pea gravel was easy to work with, would allow water to flow through it, and did not present the biological or chemical unknowns of some other substrates. Sparganium and Typha were considered not suitable for the project because they exhibited limited intercalary growth after harvesting. Intercalary growth is the kind shown by ordinary grass after mowing a lawn. The response of Sparganium and Typha to harvesting is to produce new shoots rather then lengthen the stubs. The time required to produce new shoots constituted an undesirably long delay. Phragmites may be acceptable but would have been impractical to obtain for the project since it grows in 1.5 - 2.0 m of water. The tough fibrous, tangled mats of rhizomes in deep water make hand digging very difficult.

Scirpus validus and S. acutus were judged the best candidates because they are easy to obtain, propagate easily, and regrow rapidly after harvesting. They also are morphologically similar to S. lacustris which has been used for similar studies in Europe.

Table 2. GREENHOUSE EXPERIMENTS ON PLANT PROPAGATION.

Exp.	Species	Substrate	Water depth above subs.	Type propagule	Success	Notes
1	River	Pea gravel	7 cm	3" root clump	(5/9) 55%	Several tops exposed
2	River	Pea gravel	7 cm	Tubers	(2/6) 33%	
3	Hardstem	Pea gravel	7 cm	Rhizomes	(0/12) 0%	
4	River	Pit run gravel	7 cm	3" root clump	(5/6) 83%	Several tops exposed
5	River	Pit run gravel	7 cm	Tubers	(3/8) 38%	
6	Hardstem	Pit run gravel	7 cm	Rhizomes	(0/12) 0%	
7	Hardstem	Pit run gravel	7 cm	3" root clump	(6/20) 30%	17 shoots/ 6 clumps
8	Phragmites	Pit run gravel	45 cm	3" root clump	(9/9) 33%	Cut above water line
9	Hardstem	Pit run gravel	45 cm	Rhizome	(0/8) 0%	
10	Hardstem	Pit run gravel	45 cm	3" root clump	(0/8) 0%	
11	River	Pit run gravel	45 cm	3" root clump	(2/6) 33%	Intact plants
12	River	Pit run gravel	45 cm	Tubers	(0/12) 0%	
13	River	Pea gravel	1 cm below surf.	Tubers	(35/85) 41%	
14	River	Pea gravel	1 cm below surf.	3" root clump	(9/9) 100%	21 shoots/ clumps/ several tops in air

Table 2 (continued). PLANT PROPAGATION.

Exp.	Species	Substrate	Water depth above subs.	Type propagule	Success	Notes
15	Hardstem	Pea gravel	1 cm below surf.	Rhizomes	(0/52) 0%	3-5 cm sections
16	River	Pea gravel	1 cm below surf.	Tubers	(5/23) 22%	
17	Phragmites	Pea gravel	1 cm below surf.	Rhizomes	(0/100) 0%	
18	Softstem	Pea gravel	1 cm below surf.	Rhizomes	(27/83 32%	63 shoots/ 27 Rhizomes
19	River	Organic soil	Field moisture	Tubers	(25/44) 57%	Shoots emerging at transplant
20	River	Organic soil	Field moisture	Tubers	(12/44) 27%	No shoots at transplant
21	Softstem	Organic soil	Field moisture	Rhizome	(14/45) 31%	Laid on surface
22	*Sparganium*	Organic soil	Field moisture	Root-shoot base	(0/18) 0%	Laid on surface
23	*Sparganium*	Organic soil	Field moisture	Root-shoot base	(0/36) 0%	Planted upright
24	*Typha latifolia*	Organic soil	Field moisture	Root-shoot base	(1/18) 6%	Upright
25	*Typha latifolia*	Organic soil	Field moisture	Root-shoot base	(2/9) 22%	Laid on surface
26	Softstem	Organic soil	Field moisture	Rhizome	(45/100) 45%	Fresh cut tops above soil
27	*Sparganium*	Organic soil	Field moisture	Root-shoot base	(0/5) 0%	
28	*Typha latifolia*	Crushed limestone	1 cm below surf.	Root-shoot base	(2/30) 7%	

Table 2 (continued). PLANT PROPAGATION.

Exp.	Species	Substrate	Water depth above subs.	Type propagule	Success	Notes
29	*Sparganium*	Crushed limestone	1 cm below surf.	Intact plants	(1/50) 2%	
30	*Sparganium*	Crushed limestone	1 cm below surf.	Root-shoot base	(1/40) 2½%	
31	Softstem	Crushed limestone	1 cm below surf.	Rhizome-shoots	(12/12) 100%	
32	Softstem	Crushed limestone	1 cm below surf.	Rhizome-shoots	(1/3) 33%	20-45 cm rhizomes
33	3 square	Pea gravel	1 cm below surf.	Tubers	(8/21) 38%	10 ppm gibberellin
34	Softstem	Pea gravel	1 cm below surf.	Rhizomes	(10/19) 52%	10 ppm gibberellin
35	*Sparganium*	Pea gravel	1 cm below surf.	Root shoots	(8/24) 33%	10 ppm gibberellin
36	*Iris*	Wire racks	at surface	Root-shoot base	(26/66) 40%	
37	River	Wire racks	at surface	Tubers	(16/20) 80%	Growth at transplant
38	River	Wire racks	at surface	Tubers	(41/94) 44%	No growth at transplant
39	Softstem	Wire racks	at surface	Rhizomes	(11/19) 58%	
40	*Sparganium*	Wire racks	at surface	Root-shoot base	(3/9) 33%	
41	*Typha latifolia*	Wire racks	at surface	Root-shoot base	(6/6) 100%	

Table 2 (continued). PLANT PROPAGATION.

xp.	Species	Substrate	Water depth above subs.	Type propagule	Success	Notes
42	*Iris*	Pea gravel	at surface	Root-shoot base	(44/54) 72%	
TOTAL					391/1254 31.2%	

Iris are easy to transplant but do not recover quickly from cutting and, as they are not usually found in large clones in nature, it is difficult to secure large quantities for transplanting. Iris pseudacorus has been used in Europe, however, to "remove" coliform bacteria, so the genus was included in this study.

Of the seven species examined in culture technique experiments, four were chosen for scrutiny under wastewater loading conditions. They were: Scirpus acutus, S. validus, S. fluviatilis, and Iris versicolor.

SECTION VII

GREENHOUSE STUDIES

Field studies did not begin as soon as anticipated at the beginning of the project (summer 1972), so greenhouse experiments were undertaken as a follow up to the propagation experiments discussed in Section VI. The major goal was to see which of the four species selected in the preliminary work was most effective at purification of wastewater. Other goals included obtaining additional information about responses of the plants to various treatments and determining what retention times should be attempted in the field.

A large tray in the greenhouse was divided into five compartments or beds and then lined with plastic. The beds were 80 cm x 90 cm x 12 cm. Pea gravel having a porosity of 40% was placed to a depth of seven cm in each bed. Each bed had a collection well to facilitate draining and sampling. The beds were numbered and planted as follows: Bed 1 - *Iris*; Bed 2 - control (no plants); Bed 3 - hardstem bulrush; Bed 4 - softstem bulrush; Bed 5 - softstem bulrush. The beds were batch fed chlorinated primary effluent collected once or more per week at the Oshkosh, Wisconsin (Winnebago County) municipal wastewater treatment plant. Effluent was stored temporarily in a refrigerated vault and measured amounts were added to the beds daily Monday through Friday. Prior to feeding each day an amount of water was drained from each bed so that the water level after feeding should be flush with the gravel surface. Each bed had a capacity of 21 liters.

An experiment was conducted to see how the quality of effluent varied with retention time. Analyses were performed twice weekly on influent and effluent for retention times of 1.5, 3, and 5 days. Parameters included BOD, COD, pH, conductivity, orthophosphate, and total phosphorus. Evapotranspiration losses were estimated by determining the difference between the influent and effluent volumes. Since day length is short in winter, artificial light was employed (in addition to natural light) 24 hours per day. At night the light intensity was 200 - 300 foot-candles at the gravel surface. To begin the experiment, beds were allowed a colonization period (month of December 1972) during which time microcommunities could also become established. Sampling was initiated on January 2, 1973, and continued twice each week until March 26, 1973, with four weeks allocated to each of the three retention times.

Results of the retention time experiments were judged by comparing the total output (of phosphorus for example) from a bed with the total input during a time period as described in Section IV. Detailed results of analyses are presented in Appendix B. Table B-1 gives the number of liters of influent and effluent as a basis for computing total amounts of constituents. Table 3 shows a summary of the effects of the greenhouse beds on the wastewater treated by them. A significant fraction of water (about 60%) was lost by evapotranspiration (Appendix B, Table B-1). Effluent quality was obviously best with 5-day retention.

Table 3. EFFECTIVENESS OF SEVERAL SPECIES OF PLANTS AT TREATMENT OF PRIMARY EFFLUENT IN THE GREENHOUSE.

Parameter	Retention time days			Percent reduction		
		Iris	Control	Hardstem	Softstem	Softstem
BOD	5	98	97	98	98	97
	3	94	92	92	96	95
	1.5	89	90	90	88	81
COD	5	89	89	87	86	83
	3	73	75	89	85	82
	1.5	49	54	61	57	29
Orthophosphate	5	58	52	68	75	70
	3	8	2	41	63	49
	1.5	-3	-1	28	57	30
Total phosphorus	5	80	76	84	83	80
	3	34	-4	45	62	54
	1.5	30	32	59	60	51
Coliform	5	--	--	--	--	--
	3	68	80	83	88	89
	1.5	7	22	15	60	51
Total solids	5	--	--	--	--	--
	3	32	35	35	25	25
	1.5	17	24	5	-5	-14
Suspended solids	5	--	--	--	--	--
	3	61	66	69	59	57
	1.5	39	54	22	16	-15
Dissolved solids	5	54	60	60	51	44
	3	21	28	25	13	13
	1.5	13	19	2	-9	-14

Increasing retention time from 3 to 5 days improved effluent quality much more than increasing from 1.5 to 3 days. Phosphorus removal, BOD reduction, and coliform die-off were regarded as the most important parameters upon which to judge results but coliform analyses were not performed in all cases for this experiment. All beds, including the control, reduced BOD by a high percent (97-98%). The BOD of the effluent (15-22 mg l^{-1}, 5-day retention) appears high until corrected for evapotranspiration. Phosphorus removal followed a similar pattern. Seventy-six to 83% of total phosphorus was removed with 5-day retention. No pronounced difference appeared in the treatment efficiency of the beds, including the control, if total phosphorus removal and BOD reduction are considered. This suggests that if the vegetation actually plays a role in waste treatment, the effect may not be observable until retention times are lengthened beyond 5 days.

SECTION VIII

EXPERIMENTAL BASIN STUDIES

QUALITY OF EFFLUENT

Preliminary Study

The experimental basins described in Section V were used as biological systems to treat secondary effluent starting in summer, 1973. Goals included determining whether water quality was significantly improved, working out flaws in the physical facilities, allowing vegetation to become established, and observing responses of species to various treatments. Samples of influent and effluent were collected at one week intervals beginning in the late summer after elapse of a growth period. Results are presented in Table 4. For this time period conclusions are based on comparing concentrations of constituents in influent and effluent. One of the mechanical problems was with flow regulation. Thus accurate data on volumes of influent and effluent were not obtained. As a result, the mass balance flux could not be computed. Furthermore, retention time estimates are meaningless causing data to be of value mainly for deciding where the emphasis should be placed in later parts of the project.

For the ten basins collectively, BOD reduction did not show impressive differences. The control and one experimental basin gave less than

Table 4. SUMMARY OF PRELIMINARY DATA ON EFFECTIVENESS OF EXPERIMENTAL BASINS FOR TREATING SECONDARY EFFLUENT. AUGUST - OCTOBER 1973.

		BOD				COD				Total solids			
Substrate	Species	$\bar{x}$ mg l^{-1}	S.D.	n	% red.[a]	$\bar{x}$ mg l^{-1}	S.D.	n	% red.	$\bar{x}$ mg l^{-1}	S.D.	n	% red.
	Influent	18	5.8	8	--	33	6.2	5	--	770	40	3	--
Gravel	Control	11	7.6	8	39	47	17.3	4	-42	750	10	2	3
Wire	Control	9	5.8	8	50	36	6.6	4	9	730	50	4	5
Gravel	Hardstem	9	4.5	8	50	27	13.3	5	18	730	70	4	5
Wire	Hardstem	8	5.1	8	56	27	10.7	5	18	790	50	4	-3
Gravel	Softstem	9	4.8	8	50	29	11.5	4	12	730	20	3	5
Wire	Softstem	6	4.1	8	67	29	6.5	3	12	740	50	3	4
Gravel	River	7	3.0	8	61	33	14.0	5	0	770	40	4	0
Wire	River	9	3.4	8	50	35	18.9	4	6	760	70	4	1
Gravel	Iris	9	3.6	6	50	31	9.9	3	6	690	20	2	10
Wire	Iris	12	5.9	7	33	33	1.3	2	0	750	50	4	3

		Conductivity				Orthophosphate				Total phosphorus			
Substrate	Species	$\bar{x}$ umhos	S.D.	n	% red.	$\bar{x}$ mg l^{-1}	S.D.	n	% red.	$\bar{x}$ mg l^{-1}	S.D.	n	% red.
	Influent	1040	140	10	--	16.4	6.9	8	--	14.2	3.1	8	--
Gravel	Control	943	168	9	9	12.1	4.6	8	26	13.1	4.1	8	8
Wire	Control	925	129	10	11	14.3	4.4	8	13	13.5	3.8	8	5
Gravel	Hardstem	1014	85	10	3	15.6	5.1	8	5	14.1	3.7	8	1
Wire	Hardstem	927	165	10	11	12.4	4.2	8	24	13.2	3.8	8	7
Gravel	Softstem	973	148	9	6	13.8	3.2	7	16	14.2	3.2	7	0
Wire	Softstem	978	143	8	6	12.6	3.2	6	23	13.4	3.9	6	6
Gravel	River	1054	90	9	-1	15.0	2.7	8	9	15.1	2.6	8	-6
Wire	River	988	110	9	6	13.6	3.7	8	17	15.4	5.3	8	-8
Gravel	Iris	897	127	7	14	12.1	3.1	7	26	12.6	3.1	7	11
Wire	Iris	982	128	9	6	13.9	3.0	8	15	14.5	2.6	8	2

[a] Percent reductions are not adjusted for water-loss by evapotranspiration. They are based on comparison of concentrations because accurate flow data could not be obtained.

Table 4 (continued). EFFECTIVENESS OF EXPERIMENTAL BASINS FOR TREATING SECONDARY EFFLUENT.

		$\bar{x}$	Turbidity			log col	Coliform				p^H	
Substrate	Species	JTU	S.D.	n	% red.[a]	100ml-1	S.D.	n	% red[b]	p^H	S.D.	n
	Influent	7.57	3.9	11	---	5.24	5.48	6	---	7.55	.07	11
Gravel	Control	6.93	4.1	11	8	4.78	4.91	6	66	8.09	.39	11
Wire	Control	6.85	5.2	11	10	4.86	4.94	6	59	8.01	.62	11
Gravel	Hardstem	4.84	3.1	11	36	4.62	4.79	6	76	7.45	.08	11
Wire	Hardstem	4.98	3.1	11	34	5.07	5.15	6	36	7.85	.46	11
Gravel	Softstem	4.73	2.5	10	38	4.81	4.87	5	63	7.34	.09	10
Wire	Softstem	6.47	4.1	9	15	5.02	5.33	5	40	7.48	.14	9
Gravel	River	3.76	1.4	10	50	4.29	4.48	6	89	7.62	.16	10
Wire	River	5.12	3.6	10	32	5.14	5.29	6	21	7.61	.11	10
Gravel	*Iris*	9.33	9.1	8	-23	4.80	4.62	5	64	8.22	.58	8
Wire	*Iris*	5.55	2.2	10	27	4.80	4.95	6	65	7.47	.15	10

---

[a] Percent reductions are not adjusted for water-loss by evapotranspiration. They are based on comparison of concentrations because accurate flow data could not be obtained.

[b] In this case the percent reduction is computed by comparing number of colonies per 100 ml, not by comparing logarithms.

40% reduction while all the others gave 50% or more and the high was 67% by softstem (Table 4). Total phosphorus removal was very low ranging from 11% to an apparent increase. Such increases are referred to as negative removals (Table 4). Three basins showed zero or negative total phosphorus removal. A control basin ranked second best at phosphorus removal. Other parameters showed similarly unimpressive results, but working out solutions to mechanical problems dominated the summer's work and it was felt that progress in that area would allow greatly improved control of conditions in the following growing season. Correction of data for water loss by evapotranspiration would raise the percent reduction values by significant amounts and would give more realistic results.

Subjective observations coupled with the observed good BOD reduction in the field and phosphorus removal in the greenhouse led to the choice of softstem bulrush as the most promising species. Softstem displayed greatest ease of propagation and most rapid and vigorous regrowth after harvesting. Tissues of softstem did not contain a distinctly higher percent phosphorus than other species, but it appeared that in future work softstem would produce the most biomass per unit time. _Iris_ and river bulrush showed extremely poor recovery after cutting and would not have been possible to use in a project requiring repeated harvesting. Fastening plants to wire-covered frames proved to offer no advantage and, in fact, to be unnecessary. Although on some occasions, frames with vegetation in place were moved from one basin to another; the need to do so was not related to the waste treatment processes of the biota.

Solids did not accumulate on roots as anticipated so the need to backwash did not arise. A distinct drawback to the frames was that they did not provide adequate support. Tall vegetation lodged easily leading to self-shading and decomposition. For these reasons and for the sake of convenience, future work did not employ frames.

Literature review and the low level of water quality improvement achieved initially pointed to the desirability of a major design change. Five of the basins were modified by removing partitions to form a single trench (Section V) which was expected to offer a hydrologically more suitable situation. The trench (pilot plant) was planted with softstem.

TREATMENT OF SECONDARY EFFLUENT

At the beginning of the growing season in 1974, flow meters were installed on the inlet and outlet pipes of five experimental basins so that careful monitoring was possible. By this time, operation of physical facilities had become smooth and dependable. Studies were conducted on some or all of these basins during 1974 and 1975, simultaneously, with work on the pilot plant. As a routine matter, samples were collected weekly during the growing season in order to evaluate long term effectiveness of treatment of secondary effluent. Weekly grab samples, however, can fail to detect important events of diurnal or other short duration. Thus, intensive studies were carried out on several occasions, particularly, to examine the effect of harvesting on water quality.

Long Term Variation in Effluent Quality

In this work two variables were examined for gross influences on quality of effluent produced. Although softstem was quite clearly the choice of species, one basin of river bulrush was studied in addition to a control basin and three softstem basins. Retention time was the second factor. Data are presented in Appendix C, Figures C-1 to C-8.

Variation With Species --

Between June 19 and August 31, 1974, weekly samples showed that the river bulrush basin was distinctly less effective than the other basins at reducing the concentration of BOD, coliforms, and total phosphorus (Table 5). Retention time was five hours. Total phosphorus concentration was reduced 23% by the river bulrush and an average of 31% by three softstem basins (maximum 39%). BOD was reduced 84-91% by softstem but only 62% by river bulrush and 75% by the control. Results obtained by weekly sampling showed a wide range of variability (standard deviations (Table 4). Although improvement in effluent quality was not as great as anticipated it was suspected that perhaps treatment efficiency was considerably better at some times than others and that more rigorous sampling would reveal subtle changes occurring over short periods.

Variation With Retention Time --

Lack of ability to obtain retention time of more than 5 hours was a serious handicap. Success was obtained, however, below 5 hours with no difficulty and up to 16-17 hours with considerable difficulty. An attempt was made to achieve 10-day retention time. In order to lengthen retention time in this kind of system, either the input rate must be lessened or the volume contained by the basin increased. The first method is the necessary one if wastewater is to be prevented from accumulating and rising above the gravel surface. For a 5-hour retention time an input rate of 1.91 min^{-1}(0.5 gpm) was required. That was about the lower limit because the gate valves plugged with solids at low flow rates. Flow rates down to 0.41 min^{-1} (0.1 gpm) could be maintained for short periods. The 5-hour and 16-hour retention times were studied in 1974 and 1975, respectively, and the 10-day retention was attempted at the end of 1975.

BOD reduction did not change as retention time increased (Table 6). Removal was in the range of 71-79% for both control and bulrush basins at each of the three retention times except for 91% removed in the softstem bulrush basin at 5-hour retention. Phosphorus removal was about the same for 5-hour (no-free-standing water) and 10-day (free-standing water) and higher for the 16-hour (no-free-standing water) retention time. The bulrush basin removed 44% of the load it received compared to 81% for the control. But in absolute terms, the bulrush basin removed 0.3 kg compared to 0.4 kg for the control (Appendix C, Table C-3). Thus, the difference between 44% and 81% is misleading. The explanation is in the fact that the load of total phosphorus applied to the bulrush basin was 1.4 times as great as that applied to the

Table 5. EFFECTIVENESS OF EXPERIMENTAL BASINS IN TREATMENT OF SECONDARY EFFLUENT. SUMMER 1974. FIVE-HOUR RETENTION.

	Influent load			Effluent load			% reduction[b]
	mg l^{-1}[a]	l	kg	mg l^{-1}[a]	l	kg	
BOD							
Control	49.5	63948	3.2	14.3	56514	0.8	75
Softstem	49.5	51045	2.5	10.5	38883	0.4	84
Softstem	49.5	67449	3.3	6.7	60594	0.4	88
River	49.5	75166	3.7	18.4	73909	1.4	62
Softstem	49.5	85911	4.3	4.8	77237	0.4	91
COD							
Control	41.5	63948	2.7	33.0	56514	1.9	30
Softstem	41.5	51045	2.1	29.9	38883	1.2	43
Softstem	41.5	67449	2.8	28.1	60594	1.7	39
River	41.5	75166	3.1	27.5	73909	2.0	35
Softstem	41.5	85911	3.6	17.6	77237	1.4	61
Orthophosphate							
Control	13.4	63948	0.9	10.4	56514	0.6	34
Softstem	13.4	51045	0.7	10.6	38883	0.4	43
Softstem	13.4	67449	0.9	10.4	60594	0.7	23
River	13.4	75166	1.0	11.4	73909	0.9	10
Softstem	13.4	85911	1.2	10.6	77237	0.8	33
Total phosphorus							
Control	13.8	63948	0.9	10.8	56514	0.6	33
Softstem	13.8	51045	0.7	11.1	38883	0.4	39
Softstem	13.8	67449	0.9	12.1	60594	0.7	22
River	13.8	75166	1.1	11.5	73909	0.9	23
Softstem	13.8	85911	1.2	10.4	77237	0.8	33

[a] Concentrations are averages of values obtained by sampling each week during the growing season.

[b] Water balance data are given in Appendix C, Table C-5.

control. The application of a greater load to the bulrush basin means that the retention was lessened. In terms of concentration, the influent and effluent did not differ much in most cases. The removal of phosphorus only becomes apparent upon taking water loss by evapotranspiration into account.

Short Term Variation in Effluent Quality

Three studies were conducted in 1974 to examine short term variation in influent and effluent quality. Samples were collected each four hours for 72 hours (Appendix C, Figures C-9 to C-15 and Tables C-1 and C-2) for the purpose of determining whether important fluctuations in influent and effluent quality were occurring and to tell, if possible, how the experimental basins were coping with a variable influent. Bulrushes were harvested between the first two studies to see whether harvesting altered the apparent effectiveness of the experimental basins. The third study served as a follow-up designed to detect improvement in treatment efficiency which might result from recovery of the vegetation which had been harvested. Results of the three studies are shown in Tables 7 through 9. Retention time was 5 hours. Excellent control over volume loading rates was possible. Since all sampling was done by hand, the person on the site had only to make a check on flow rates each 4 hours to insure accuracy. Careful control of volume loading rate apparently did not insure uniform outflow rate as would have been

Table 6. PERCENT REDUCTION IN BOD, TOTAL SOLIDS AND TOTAL PHOSPHORUS. SUMMARIZED FROM TABLES 5, 12 AND APPENDIX C, TABLES C-3 AND C-4.

Effluent	Retention time	BOD Cont.	BOD Bulr.	Total solids Cont.	Total solids Bulr.	Total P Cont.	Total P Bulr.
Secondary	5-hour	75	91	-17	25	33	31
Secondary	16-hour	77	72	57	49	81	44
Secondary	10-day	71	79	43	29	36	32
Primary	10-day	83	87	37	18	36	25

Table 7. EFFECTIVENESS OF EXPERIMENTAL BASINS IN TREATMENT OF SECONDARY EFFLUENT DURING WEEK PRIOR TO HARVESTING. FIVE-HOUR RETENTION.

Parameter	Basin	Influent load[a] mg l^{-1}	liters	kg	Effluent load[a] mg l^{-1}	liters	kg	% reduction
BOD	Control	38	7843	0.30	5	7865	0.04	87
	Bulrush	38	7835	0.30	5	7067	0.04	87
COD	Control	42	7843	0.33	31	7865	0.24	27
	Bulrush	42	7835	0.33	36	7067	0.25	24
Total phosphorus	Control	23	7843	0.18	18	7865	0.14	22
	Bulrush	23	7835	0.18	21	7067	0.15	17
Dissolved solids	Control	916	7843	7.20	930	7865	7.30	-1
	Bulrush	916	7835	7.20	910	7067	6.40	11

[a] Concentrations are averages of values obtained sampling every four hours for four days.

Table 8. EFFECTIVENESS OF EXPERIMENTAL BASINS IN TREATMENT OF SECONDARY EFFLUENT DURING FIRST WEEK AFTER HARVESTING. FIVE-HOUR RETENTION.

Parameter	Basin	Influent load mg l^{-1}	liters	kg	Effluent load mg l^{-1}	liters	kg	% reduction
BOD	Control	65	5352	0.35	9	7059	0.06	83
	Bulrush	65	6022	0.39	5	5840	0.03	92
Total phosphorus	Control	21	5352	0.11	18	7059	0.13	-18
	Bulrush	21	6022	0.13	16	5840	0.09	31
Total solids	Control	988	5352	5.30	873	7059	6.20	-17
	Bulrush	988	6022	5.90	761	5840	4.40	25
Dissolved solids	Control	758	5352	4.10	744	7059	5.30	-29
	Bulrush	758	6022	4.60	687	5840	4.00	13
Suspended solids	Control	232	5352	1.20	168	7059	1.20	0
	Bulrush	232	6022	1.40	75	5840	0.44	69

Table 9. EFFECTIVENESS OF EXPERIMENTAL BASINS IN TREATMENT OF SECONDARY EFFLUENT DURING THIRD WEEK AFTER HARVESTING. FIVE-HOUR RETENTION.

Parameter	Basin	Influent load mg l^{-1}	liters	kg	Effluent load mg l^{-1}	liters	kg	% reduction
BOD	Control	40	6109	0.24	4	4705	0.02	92
	Bulrush	40	6408	0.26	3	7517	0.02	92
Total phosphorus	Control	22	6109	0.13	18	4705	0.08	38
	Bulrush	22	6408	0.14	18	7517	0.16	-14
Total solids	Control	860	6109	5.30	829	4705	3.90	26
	Bulrush	860	6408	5.50	909	7517	6.80	-24
Dissolved solids	Control	762	6109	4.70	740	4705	3.50	26
	Bulrush	762	6408	4.90	749	7517	5.60	-14
Suspended solids	Control	93	6109	0.57	89	4705	0.42	26
	Bulrush	93	6408	0.60	165	7517	1.20	-100

expected. In both the pre-harvest and the first post-harvest studies, the control basin yielded more water than it received. The bulrush basin yielded more water than it received in the second post-harvest study (Tables 7-9). This finding revealed a greater than anticipated ability of the basins to buffer flow rates which were not carefully checked prior to the beginnings of the intensive studies.

Results of the tests using four-hour sampling intervals showed that the variability of the influent was considerably greater than that of the effluent although the variability was high in the effluent for some parameters. Distinct events changing with time of day could not be identified. A summary of data for the three studies (Table 10) also shows that harvesting the bulrushes did not affect changes in quality of effluent. In fact, average values of percent reduction scatter widely for all parameters except BOD (83-92%). The negative percent reductions result from the excess of effluent volume over influent volume in some cases (Appendix C, Table C-2). For example, in the second post-harvest study, the total phosphorus concentration was lowered by both the control and the bulrush basin from 22 to 18 mg l^{-1}. The bulrush basin had 17% more effluent than influent however, so in spite of a reduction of 18% in concentration (22 mg l^{-1} to 18 mg l^{-1}), there was more phosphorus leaving the basin than going in during the three-day period.

Table 10. EFFECT OF HARVESTING BULRUSHES ON TREATMENT EFFICIENCY. PERCENT REDUCTIONS ARE SUMMARIZED FROM TABLES 7, 8, and 9.

Parameter	Pre-harvest		First post-harvest		Second post-harv.	
	Control	Bulrush	Control	Bulrush	Control	Bulrush
BOD	87	87	83	92	92	92
Total phosphorus	22	17	-18	31	38	-14
Total solids	--	--	-17	25	26	-24
Dissolved solids	-1	11	-29	13	26	-14
Suspended solids	--	--	0	69	26	-100

TREATMENT OF PRIMARY EFFLUENT

Primary effluent was treated in one control and in one bulrush experimental basin from August 21 to November 4, 1975, and in the pilot plant for the same period. Major emphasis was put on the pilot plant.work. The flow regulation difficulty mentioned earlier kept the desired 10-day retention time from being achieved with accuracy. The goal of treating primary effluent in experimental basins was to see whether the system behaved differently than it did with secondary effluent. Unfortunately, it was not possible to achieve 10-day retention time without having standing water and surface flow.

On the mass balance basis, treatment of primary effluent was not as good as treatment of secondary effluent in terms of percent reduction except in the case of BOD (Table 6). BOD reduction was nearly 10% greater in primary (83-87%) than in secondary effluent (71-79%). Interpretation of this result is complicated by the fact that the load on the bulrush basin

Table 11. WATER BALANCE DATA FOR EXPERIMENTAL BASINS. 1975.
(liters)

	Influent	Rainfall	Total effluent	% evapotranspiration
Secondary Effluent Sixteen-hour retention				
Control	19784	1308	11533	45.3
Bulrush	26866	1308	18887	32.9
Secondary Effluent Ten-day retention				
Control	21397	2422	13013	45.3
Bulrush	34337	2422	20590	43.9
Primary Effluent Ten-day retention				
Control	14576	5962	11979	41.6
Bulrush	35734	5962	32808	21.3

was about 2.5 times as great as on the control basin (Table 11) due to very poor flow rate regulation in this peripheral experiment. Examination of the number of kilograms of BOD removed shows that the bulrush basin removed 2.5 times as much BOD as the control but the percent reductions are nearly identical (Table 12). In the case of secondary effluent, there was a loading differential of 1.6 times as much BOD on the bulrush basin as on the control. In that case the bulrush basin removed 1.8 times as much BOD. For this parameter the bulrush basin distinctly did the best job because it removed the same fraction of the load from the primary effluent as the control in spite of a much heavier load. Roughly, the same number of liters was lost by evapotranspiration from each of the two basins even though one was loaded at a higher rate (Table II). This accounts for the difference between evapotranspiration loss of 42% in the control and 21% in the more heavily loaded bulrush basin.

Phosphorus (total) was not removed to nearly such a great extent as BOD. The control and bulrush basins removed 36% and 25%, respectively. However, the bulrush basin removed 1.7 times as much phosphorus as the control while being loaded with 2.5 times as much (Table 12). Obviously, both basins did not have the same retention time. It seems safe to assume that the bulrush basin would have, at worst, removed phosphorus at the same rate as the control under the same loading rate.

Removal of total solids from primary effluent was less efficient than from secondary effluent. Best total solids removal was achieved when

Table 12. EFFECTIVENESS OF EXPERIMENTAL BASINS FOR TREATMENT OF PRIMARY EFFLUENT. TEN-DAY RETENTION.

		Influent load			Effluent load			
Parameter	Basin	mg l^{-1}	liters	kg	mg l^{-1}	liters	kg	% reduction
BOD	Control	320	14576	4.70	65	11979	0.78	83
	Bulrush	320	35734	11.40	47	32808	1.50	87
COD	Control	400	14576	5.80	130	11979	1.60	72
	Bulrush	400	35734	14.30	110	32808	3.60	75
Orthophosphate	Control	26	14576	0.38	20	11979	0.24	37
	Bulrush	26	35734	0.93	20	32808	0.66	29
Total phosphorus	Control	27	14576	0.39	21	11979	0.25	36
	Bulrush	27	35734	0.96	22	32808	0.72	25
Total solids	Control	1066	14576	15.50	814	11979	9.80	37
	Bulrush	1066	35734	38.10	952	32808	31.20	18
Suspended solids	Control	97	14576	1.40	37	11979	0.44	69
	Bulrush	97	35734	3.50	19	32808	0.62	82
Dissolved solids	Control	969	14576	14.10	778	11979	9.30	34
	Bulrush	969	35734	34.60	932	32808	30.60	12

wastewater had to pass through gravel (Table 6) even though retention time was shorter. Primary effluent was not treated with a short enough retention time, however, to study solids removal under the no-free-standing-water condition.

SECTION IX

PILOT PLANT STUDIES

Wastewater was treated in the pilot plant in 1974 and 1975. The 1974 growing season was allowed to pass mainly as a growth period for the softstem bulrushes. Limited sampling of effluent was conducted in 1974. In 1975, samples were collected weekly at each of four depths at each of three sites along the length of the pilot plant (Figure 6) as well as of the influent. One intensive three-day study was conducted. The partitions dividing the pilot plant into three sections were removed August 6, 1975. Sampling in 1975 was according to the schedule shown in Table 13.

Table 13. 1975 SAMPLING SCHEDULE FOR PILOT PLANT.

Dates	Nature of effluent	Depth of discharge
June 15 - July 17	Secondary	60 cm
July 17 - August 6	Secondary (Partitions removed)	15 cm
August 6 - August 21	Secondary	60 cm
August 21 - November 4	Primary	60 cm

Retention time was calculated to have been 10 days (Section V) but the realized time was probably somewhat less. The variables altered in this work were the nature of the wastewater (secondary, primary) and depth at which effluent was withdrawn at the downstream end.

Early results on secondary effluent indicated promising BOD reduction ability (92%) but less favorable total phosphorus removal (35%, Table 14 and Appendix D, Table D-1). Since these figures were taken soon after construction of the pilot plant they were questioned. The following summer, BOD reduction dropped to the 30-38% range for treatment of secondary effluent (Tables 15-17). Removal of the partitions did not change the rate of BOD reduction. Occasional checks at different locations and depths in the pilot plant showed that no dissolved oxygen was present at any time.

Table 14. EFFECTIVENESS OF THE PILOT PLANT IN TREATING SECONDARY EFFLUENT. SUMMER 1974.

	Influent load			Effluent load			% reduction
Parameter	mg l^{-1}	liters	kg	mg l^{-1}	liters	kg	
BOD	50.0	607227	30.0	4.0	604468	2.4	92
COD	42.0	607227	26.0	24.0	604468	14.5	44
Orthophosphate	13.4	607227	8.1	8.5	604468	5.1	37
Total phosphorus	13.9	607227	8.4	9.0	604468	5.4	35

Phosphorus removal was better than in the experimental basins but not as good as it was in the greenhouse. During July 17 - August 21, 1975, 60-64% of total phosphorus was removed from secondary effluent in two experiments (Tables 16, 17). Distribution of the phosphorus into components of the pilot plant ecosystem is discussed below.

Primary effluent was treated in the pilot plant late in the growing season (beginning August 21). BOD reduction of 77% and total phosphorus removal of 37% were observed (Table 18 and Appendix D, Table D-2). This level of treatment was roughly comparable to secondary treatment given by the municipal treatment plant. Secondary effluent from the municipal plant had BOD of 19-50 mg 1^{-1} (Tables 15-17) and total phosphorus of 23-24 mg 1^{-1}. The effluent from the pilot plant had BOD of 72 mg 1^{-1} and total phosphorus of 17 mg 1^{-1}. Based on these concentrations, the pilot plant effluent is higher in BOD and slightly lower in total phosphorus than the secondary effluent. The lower total phosphorus (17 mg 1^{-1}) was not as low as the concentration found in secondary

Table 15. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT. EFFLUENT DRAWN FROM DEPTH OF 0.60 m. JUNE 5 - JULY 17, 1975.

	Influent load			Effluent load			
Parameter	mg 1^{-1}	liters	kg	mg 1^{-1}	liters	kg	% reduction
BOD	19	119200	2.3	15	108255	1.6	30
COD	38	119200	4.5	41	108255	4.4	2
Orthophosphate	23	119200	2.7	14	108255	1.5	44
Total phosphorus	24	119200	2.9	15	108255	1.6	45
Total solids	827	119200	98.6	1253	108255	135.6	-38
Suspended solids	70	119200	8.3	147	108255	15.9	-92
Dissolved solids	757	119200	90.2	1107	108255	119.8	-33

effluent after passing through the pilot plant (12-15 mg 1^{-1}).

Numerous data are presented in Appendix D, Tables D-3 to D-7.

Table 16. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT. EFFLUENT DRAWN FROM DEPTH OF 0.15 m. JULY 17 - AUGUST 6, 1975.

	Influent load			Effluent load			% reduc-
Parameter	mg 1^{-1}	liters	kg	mg 1^{-1}	liters	kg	tion
BOD	28	57036	1.6	25	39376	1.0	38
COD	115	57036	6.6	95	39376	3.7	44
Orthophosphate	25	57036	1.4	12	39376	0.5	64
Total phosphorus	24	57036	1.4	12	39376	0.5	64
Total solids	1028	57036	586.6	1117	39376	439.8	25
Suspended solids	54	57036	3.1	18	39376	0.7	77
Dissolved solids	974	57036	55.6	1099	39376	43.3	22

Table 17. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT AFTER REMOVAL OF PARTITIONS. EFFLUENT DRAWN FROM DEPTH OF 0.60 m. AUGUST 6 - AUGUST 21, 1975

Parameter	Influent load mg l^{-1}	liters	kg	Effluent load mg l^{-1}	liters	kg	% reduction
BOD	50	44924	2.2	43	35919	1.5	33
COD	72	44924	3.2	58	35919	2.1	34
Orthophosphate	20	44924	0.9	14	35919	0.5	44
Total phosphorus	23	44924	1.0	12	35919	0.4	60
Total solids	1066	44924	47.9	845	35919	30.4	37
Dissolved solids	970	44924	43.6	825	35919	29.6	32
Suspended solids	97	44924	4.4	19	35919	0.7	84

Table 18. EFFECTIVENESS OF PILOT PLANT IN TREATING PRIMARY EFFLUENT. AUGUST 21 - NOVEMBER 4, 1975.

Parameter	Influent load mg l^{-1}	liters	kg	Effluent load mg l^{-1}	liters	kg	% reduction
BOD	317	188273	59.7	72	187376	13.5	77
COD	401	188273	75.5	117	187376	21.9	71
Orthophosphate	26	188273	4.9	17	187376	3.2	35
Total phosphorus	27	188273	5.1	17	187376	3.2	37
Total solids	973	188273	183.2	1156	187376	216.6	-18
Suspended solids	42	188273	7.9	32	187376	6.0	24
Dissolved solids	932	188273	175.5	1124	187376	210.6	-20

SECTION X

PHOSPHORUS DISTRIBUTION AND REMOVAL

EXPERIMENTAL BASINS

Theoretically, large quantities of phosphorus and other nutrients which are taken up by emergent aquatic plant shoots could be removed by harvesting in a manner similar to cutting hay in agricultural practice. Studies of natural stands have shown that highest concentrations of phosphorus occur in young tissue and that concentrations decrease with increasing age of tissue. This suggests that the quantity of phosphorus removed can be maximized by frequent harvesting so that plant tissues are not permitted to mature. Studies of the effect of harvesting on a natural marsh near Seymour, Wisconsin (Hanseter, 1975), have confirmed that considerable quantities of phosphorus can be removed by harvesting. Repeated harvest during the growing season can increase the removal of phosphorus by a factor of three.

On August 3, October 1, and October 23 (after frost), 1973, plant shoots were harvested (by cutting above the intercalary meristem) from quadrats in the eight experimental basins. Generally, it was found that the most rapid recovery after harvesting and, thus, the greatest potential for phosphorus removal was by the softstem bulrush (Table 19). The *Iris* produced very little biomass, and only negligible amounts of phosphorus could be removed. Two to seven grams P m^{-2} were removed from the six basins containing bulrushes. Examination of the plants on October 23 showed almost all of the growth of the river bulrush was from old shoots, (intercalary meristimatic growth from previously harvested shoots). In the hardstem and softstem old shoots and new shoots (arising from the rhizomes) contributed about equally.

During 1974, the plants in the four experimental basins containing gravel substrate were harvested on four occasions between June 17 and September 23. In the two basins containing softstem bulrush, 3.51 and 3.83 g P m^{-2} were removed (Table 20). In the river bulrush basin only 1.13 g P m^{-2} were removed and only 0.99 g P m^{-2} were removed from the *Iris* basin.

A removal of 3.5 g P m^{-2} is equivalent to 35 Kg P ha^{-1} (31.25 lb $acre^{-1}$). This amount of phosphorus is equal to that contributed by 33 persons in four months (the growing season) if a *per capita* load of 3 lb *per annum* is assumed (Steward, 1970). This also represents the annual removal capacity since it encompasses the entire growing season. Thus, removal capacity of only 10 persons per acre could be assumed on a year-round basis.

The frequency of harvesting had a similar effect on the total amount of plant tissue generated in a single year as Hanseter reported for a natural marsh (1975). In experimental basin number 3 (softstem bulrush), only about three-fourths as much tissue was removed during four harvests in 1974 as in two late season harvests in 1975 (Table 21). However, 5, 6 times as much phosphorus was removed by the more frequent harvesting in 1974.

Table 19. PHOSPHORUS REMOVAL BY HARVESTING OF PLANT SHOOTS FROM EXPERIMENTAL BASINS, 1973. (g P m^{-2})

Basin number[a]	Plant Species	Substrate	Aug. 3	Oct. 1	Oct. 23 New shoots	Oct. 23 Old shoots	Total
2	Hardstem bulrush	Wire rack	0.28	1.72	0.31	0.33	2.64
3	Hardstem bulrush	Gravel	1.11	1.07	0.26	0.59	3.03
4	Softstem bulrush	Wire rack	2.00	4.87	0.46	0.25	7.58
5	Softstem bulrush	Gravel	1.78	1.75	0.38	0.46	4.37
6	River bulrush	Wire rack	3.74	0.38	0.18	0.43	4.73
7	River bulrush	Gravel	0.92	0.75	0.10	0.19	1.96
9	Iris	Gravel	0.002	0.0002	0.001	0.16	0.16
10	Iris	Wire rack	0.007	0.005	no growth	0.52	0.52

[a] Basin numbers 1 and 8 were control basins having gravel and wire racks, but no plants.

Table 20. PHOSPHORUS REMOVAL BY MULTIPLE HARVESTING OF EXPERIMENTAL BASINS IN 1974. (g P m^{-2})

Date	Softstem bulrush	Softstem bulrush	River bulrush	Softstem bulrush
June 17	1.53	1.86	0.58	--
July 19	1.32	1.06	0.33	0.37
August 8	0.30	0.61	0.16	0.39
September 23	0.36	0.30	0.06	0.23
Total	3.51	3.83	1.13	0.99

Water quality data indicated that more phosphorus was being removed by the system than was present in the harvestable plant tissue. To determine where the phosphorus was located, triplicate cores were taken from each basin at the time of harvesting in June, September, and December 1974 and in June and November of 1975. Only 0 to 14% of the total phosphorus was present in the harvestable plant tissue of any basin at any one time (Table 22). From 34 to 80% of the total phosphorus in the system was usually incorporated in the total harvestable and unharvestable plant biomass during the growing season. The remainder was retained as organic and inorganic precipitates and microflora in the gravel substrate. During the growing season of 1974, the phosphorus in the microflora-substrate complex ranged from 1-11 g m^{-2} and averaged about 7 g m^{-2}. Between September and December of 1974, the concentration of phosphorus in the basins dropped to much lower levels, indicating a loss from the system after the autumn frosts. The only exception to

Table 21. EFFECT OF HARVESTING FREQUENCY ON STANDING CROP AND PHOSPHORUS REMOVAL FROM AN EXPERIMENTAL BASIN.

Year	Number harvests	Standing crop harvested (g dw m^{-2})	Phosphorus removal (g P m^{-2})
1974	4	1689.0	3.51
1975	2 (Aug; Oct)	2433.7	0.63

this pattern was Basin 9 in which the phosphorus was retained in the substrate. This basin received more sediments from erosion of the clay rich embankments than the other basins. The phosphorus retention capacity of the clay may explain the unexpected phosphorus retention of the basin after frost.

Presuming that the loss of phosphorus from the substrate after freezing is normal and predictable behavior, this loss could be a feature which would permit the removal of 15 or more g P m^{-2} each year. Removal could be accomplished by discontinuing the flow through the system at the time of the first heavy frost. The system could then be flushed so the concentrated washings could be collected and treated by conventional means. The maximum loading that such a system could retain is undetermined, but after receiving primary effluent for about 2½ months, more than 20 g P m^{-2} was present in each of the two experimental basins. While the last data are from cores taken about the same time as in 1974, no heavy frost had yet occurred in 1975, and it is reasonable to believe that most of the phosphorus accumulated since June was still present.

Table 22. DISTRIBUTION OF PHOSPHORUS IN PLANTS AND SUBSTRATE IN EXPERIMENTAL BASINS.

	1974						1975			
	June 17		Sept. 23		Dec. 4		June 2		Nov. 18	
	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%
Basin 3 Softstem Bulrush										
Harvested shoots	1.53	8.11	0.36	1.83	0.00	0.00	[a]		0.63	2.31
Unharvested shoots	1.83	9.70	2.46	12.53	0.75	12.30	1.56	17.70	0.84	3.08
Rhizomes	3.04	16.12	5.45	27.76	2.32	38.03	1.44	16.34	0.67	2.46
Roots	1.25	6.63	3.92	19.97	1.86	30.49	0.86	9.76	1.69	6.20
Total biomass	7.65	40.56	12.19	62.10	4.93	80.82	3.86	43.82	3.83	14.08
Gravel	11.21	59.94	7.44	37.90	1.17	19.18	4.95	56.18	23.39	85.92
	18.86	100.00	19.63	100.00	6.10	100.00	8.81	100.00	27.22	100.00
Basin 5 Softstem Bulrush										
Harvested shoots	1.86	14.09	0.30	0.75	0.00	0.00	[a]		[b]	
Unharvested shoots	0.82	6.21	1.74	10.16	0.58	7.82	0.98	7.46		
Rhizomes	1.42	10.76	3.12	18.21	2.30	28.86	2.18	16.59		
Roots	0.35	2.65	3.41	19.91	2.68	33.63	1.53	11.64		
Total biomass	4.45	33.71	8.57	50.03	5.56	69.76	4.69	35.69		
Gravel	8.75	66.29	8.56	49.97	2.41	30.24	8.45	64.31		
Total	13.20	100.00	17.13	100.00	7.97	100.00	13.14	100.00		
Basin 7 River Bulrush										
Harvested shoots	0.58	1.54	0.06	0.44	0.00	0.00	[a]		[b]	
Unharvested shoots	3.00	7.97	2.08	15.42	0.79	9.86	0.54	9.12		
Rhizomes	23.78	63.18	3.04	22.54	1.61	20.10	0.48	8.11		
Roots	2.58	6.85	5.56	41.22	4.53	56.55	0.21	3.55		
Total biomass	29.94	79.54	10.74	79.61	6.93	86.52	1.23	20.78		
Gravel	7.70	20.46	2.75	20.39	1.08	13.48	4.69	79.22		
Total	37.64	100.00	13.49	100.00	8.01	100.00	5.92	100.00		

[a] Harvested values combined with unharvested values.
[b] Experiment terminated.

Table 22 (continued). PHOSPHORUS IN EXPERIMENTAL BASINS.

	1974						1975			
	June 17		Sept. 23		Dec. 4		June 2		Nov. 18	
	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%	g P m^{-2}	%
Basin 9 Softstem Bulrush										
Harvested shoots	a		0.23	1.80	0.00	0.00	a		b	
Unharvested shoots	3.31	36.74	0.61	4.77	0.57	4.83	0.41	7.72		
Rhizomes	1.63	18.09	1.89	14.78	1.07	9.08	0.17	3.20		
Roots	0.91	10.10	1.84	14.39	3.19	27.06	0.17	3.20		
Total biomass	5.85	64.93	4.57	35.73	4.83	40.97	0.75	14.12		
Gravel	3.16	35.07	8.22	64.27	6.96	59.03	4.56	85.88		
Total	9.01	100.00	12.79	100.00	11.79	100.00	5.31	100.00		
Basin 1 Control										
Gravel	7.91	100.00	5.18	100.00	0.38	100.00	4.35	100.00	21.6	100.00

[a] Entire plants were removed with the cores and are considered to be unharvested shoots.
[b] Experiment terminated.

PILOT PLANT

A study similar to the one in the experimental basins was done on the distribution of phosphorus in the pilot plant. Difficulty was encountered in securing acceptable cores, however, (Section IV) so no samples were taken until after all experiments had been terminated. A record was made of tissue harvested, then cores were taken on December 5, 1975. At that time, there was an average of about 18 g P m^{-2} in the substrate (Table 23, 24). Considerable variation occurred, however, and there was a large concentration of phosphorus in the uppermost 15 cm of gravel near the influent. This high concentration was not, however, associated with an accumulation of solids or dry matter at that end of the basin, as none were present (Appendix E, Tables E-1 and E-2).

Table 23. PHOSPHORUS DISTRIBUTION IN GRAVEL OF PILOT PLANT AFTER TWO SUMMERS. (g P m^{-2})

Depth	Basin A	Basin B	Basin C	Mean
0-15 cm[a]	17.58	3.58	5.52	8.89
15-30 cm[b]	5.14	1.81	7.27	4.74
30-45 cm[c]	4.17	0.71	1.97	2.28
45-60 cm[c]	4.17	0.71	1.97	2.28
Total	30.72	6.81	16.74	18.09

[a] Each value is the mean of three.
[b] Each value is the result of analysis of a single sample.
[c] Each value represents a single sample taken at 45 cm and assumed to be representative of both depth intervals.

In spite of a very large standing crop, especially in Basin A, the total amount of phosphorus removed by harvesting was only about 2.09 g m^{-2} because the two harvests were made late in the growing season. The high yield in Basin A (2.67 g P m^{-2}) compared to the yield in Basin C (0.69 g P m^{-2}, Table 24) is indicative of a much more dense stand of plants at the influent end (Appendix E, Table E-3). There was an average of 420 shoots m^{-2} (1.20 m tall and 0.73 cm diameter) at the influent, while there were only 240 shoots m^{-2} (0.79 m tall and 0.57 cm diameter) at the effluent end. The reason for the apparent difference in vogor at the ends of the pilot plant is probably that much of the vegetation at the downstream end was killed accidentally by desiccation in 1974 and was replaced by new plants in 1975. The overall stand was quite substantial, however, with 4 - 9 g P m^{-2} in the total biomass.

Table 24. DISTRIBUTION OF PHOSPHORUS IN PILOT PLANT DURING 1975. (g P m^{-2})

Sample	Date	Basin A	Basin B	Basin C	Mean	%
Harvested shoots[a]	Aug. 1	2.12	2.76	0.48	1.80	7.14
Harvested shoots[a]	Sept. 24	0.45	0.20	0.21	0.29	1.15
Unharvested shoots[b]	Dec. 5	0.82	0.79	0.49	0.70	2.78
Rhizomes	Dec. 5	2.91	1.61	0.64	1.72	6.82
Roots	Dec. 5	2.64	4.07	1.12	2.61	10.41
Gravel substrate	Dec. 5	30.72	6.81	16.74	18.09	71.76
Total		39.66	17.92	19.68	25.21	100.00

[a] Each value is the mean of three 1 m^{2} quadrat samples.
[b] Each value is the mean of three 12.6 cm diameter cores.

This is comparable to total biomass in the experimental basins (Table 22). The total phosphorus retention capacity of the pilot plant system is probably in excess of 40 g P m^{-2}, primarily because of the great volume of the gravel substrate. None of the phosphorus in the substrate below 30 cm is likely to be available to the plants since 30 cm is as deep as the roots penetrated.

SECTION XI

BRILLION MARSH STUDIES

DESCRIPTION OF BRILLION MARSH

Physical and Biological

Brillion Marsh is located in T19N and T20N, R20E, Calumet County, Wisconsin. It is in the drainage basin of the North Branch of the Manitowoc River, which flows into Lake Michigan. While the total marsh area is 15 - 18 km^2, only a portion of the northeastern area was used in this study. The study area is located in SW¼, Sec. 26; SE¼, Sec. 27; NE¼, Sec. 34; and NW¼, Sec. 35; T20N, R20E (Figure 7). It has an area of 156 ha and lies at an elevation of 805 to 807 feet (245 m) above mean sea level.

Spring Creek is the major stream flowing into the study area. At its point of entrance to the marsh, it has a drainage area of 31.3 km^2. Spring Creek has an open channel about 400 m long extending into the marsh. The channel is about 10 m wide and 1 - 1.5 m deep at the marsh entrance, and gradually diminishes in size as small distributaries lead into the marsh. The creek does not have a channel through the marsh for about 1400 m, until the marsh becomes narrow, at which point a channel about 10 - 15 m wide and 1 - 1.3 m deep is present. At the narrow part, the marsh is 200 m wide. Above this channel the marsh has a total drainage area of 49.7 km^2.

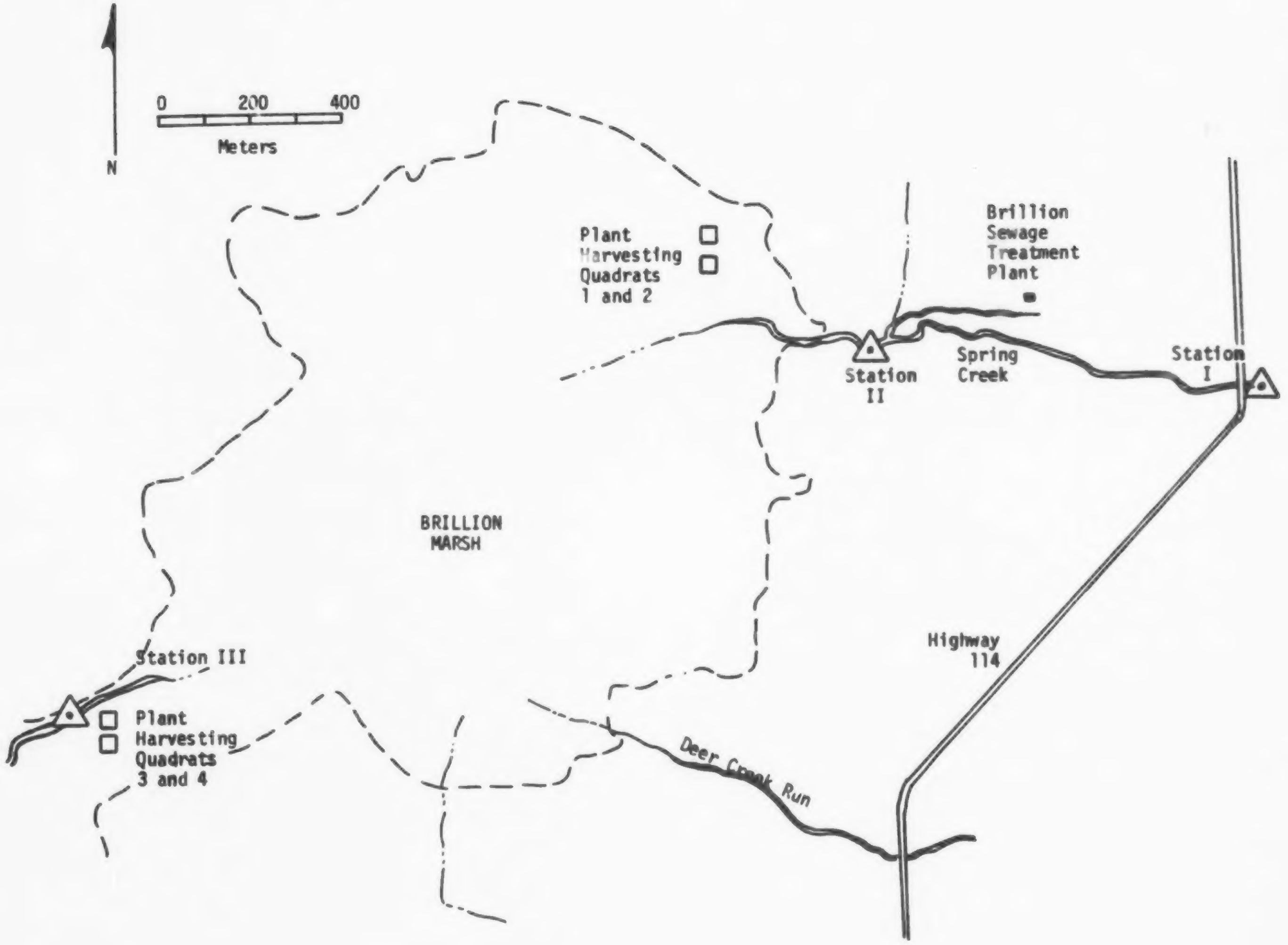


Figure 7. Location of Spring Creek and Brillion Marsh Drainage Basin.

The City of Brillion is located on Spring Creek just upstream from the marsh. Spring Creek receives effluent from the city sewage treatment plant. In addition, local industries such as a foundry and a cannery may contribute effluent at times. Agricultural runoff and urban runoff from storm sewers go into Spring Creek. There are several other streams flowing into the marsh study area. The drainage basin lies in a glaciated area with glacial tills and clays forming the predominant surficial material. The topography is flat to gently rolling.

The upper marsh has a stand of _Typha latifolia-augustifolia_ complex. _Sparganium eurycarpum_ is growing in a 1 - 30 m band along the stream channels at both ends of the marsh and in isolated low pockets of the marsh proper. Where Spring Creek enters the marsh (Figure 8, Station II), there are no submergent aquatic plants in the stream channel. This is presumably due to the high concentration of effluent from the Brillion sewage treatment plant which enters the stream from a channel 15 m upstream. Deer Creek Run which enters the marsh via a golf course south of Brillion is intermittent. There is a dredged channel from Highway 114 into the marsh. This channel contains water all year and has a diversified flora. _Sagittaria latifolia_ Willd. lines the channel, along with _Typha_ and _Sparganium_. Submergent vegetation includes _Vallisneria americana_ Michx., _Elodea canadensis_ Michx., _Potomogeton pectinatus_ L., _Ceratophyllum demersum_ L., and the filamentous alga _Oedogonium_ sp. In the dredge channel at the downstream end of the marsh (Figure 8, Station III), there is a sparse stand of _Ceratophyllum_

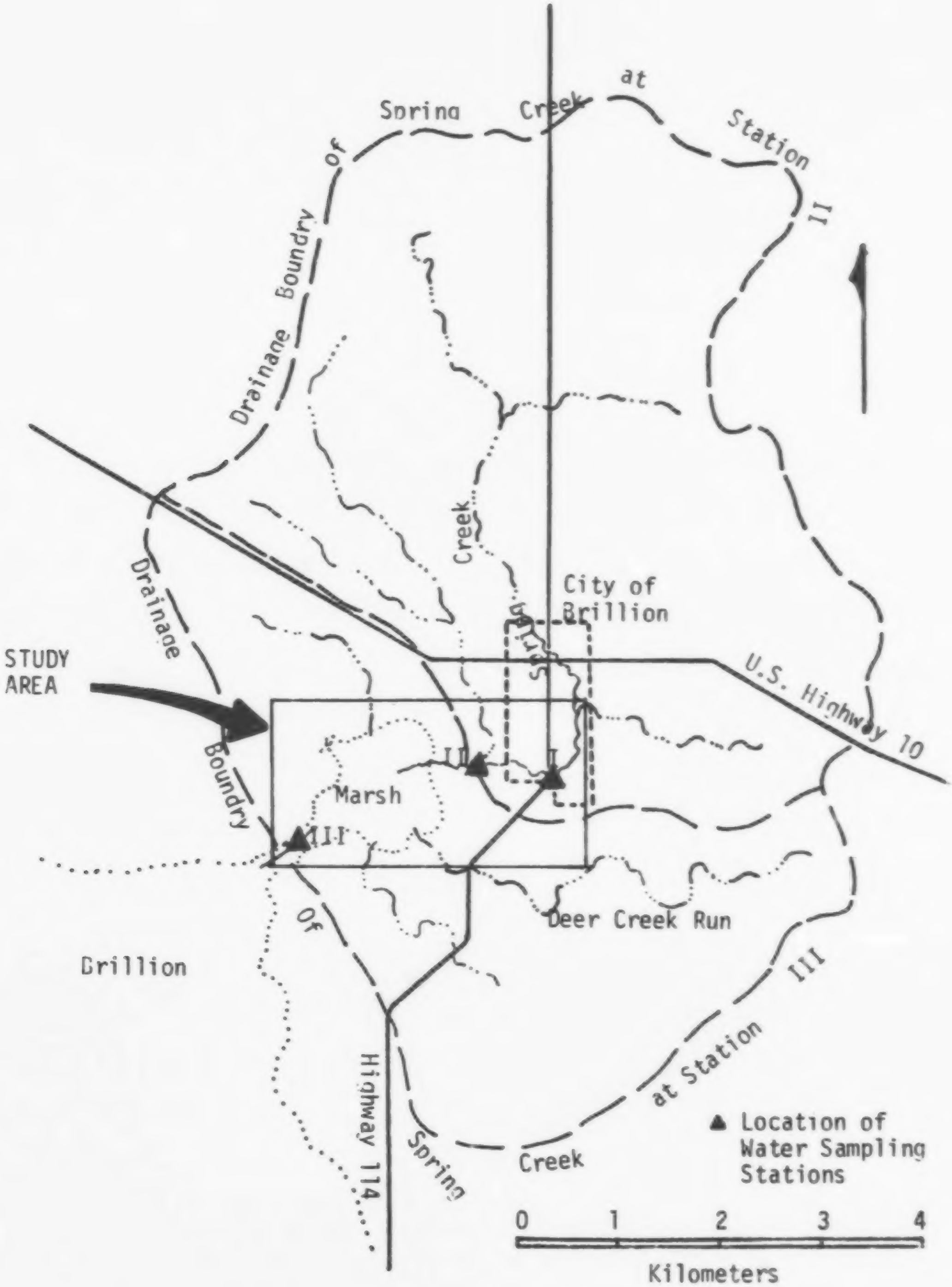


Figure 8. Map of Brillion Marsh Study Area Showing Water Sampling (△) and Plant Harvesting (▣) Sites.

demersum, with isolated shoots of Potomogeton pectinatus. Lemna covers much of the surface in late summer.

Hydrology

Runoff --

The Brillion area receives a yearly average of 73 cm of precipitation. About 54 cm of this is lost through evapotranspiration, with an average runoff of 19 cm. The U.S. Geological Survey has made an estimation of the low-flow of Spring Creek at Brillion of 9.6 l sec^{-1} for the seven-day low-flow with a two-year recurrence interval, $7Q_2$, and 4.8 l sec^{-1} for the seven-day low-flow with a 10-year recurrence interval, $7Q_{10}$. The monthly precipitation at Brillior for June 1974 to July 1975 is given in Table 25.

With an average runoff of 19 cm $year^{-1}$ and a drainage basin area of 31.3 km^2, the mean runoff is 0.19 m^3 $sec.^{-1}$. However, the usual runoff pattern is to have a high spring runoff and low flows the remaining months. Table 26 shows the Manitowoc River runoff for water years 1974 and 1975.

Sewage Flow --

Records obtained from the City of Brillion (population 2,588) indicate that the monthly discharge of the Brillion wastewater treatment plant ranged from 2.2×10^4 m^3 to 4.6×10^4 m^3 during the study period. Monthly flow of Spring Creek at Station II, has been estimated, where it merges with the wastewater discharge channel. The estimated values were obtained by multiplying the monthly runoff from the Manitowoc River at Manitowoc by the drainage area of the sub-basin above Brillion Marsh. The monthly sewage discharge, estimated runoff of Spring Creek at Station II, and the ratio of sewage flow to runoff are given in Table 27.

Table 25. MONTHLY RAINFALL AT BRILLION, WISCONSIN.
(cm)

Month	Year	Rainfall
June	1974	7.21
July	1974	4.52
August	1974	5.92
September	1974	3.30
October	1974	4.19
November	1974	4.39
December	1974	3.53
January	1975	3.12
February	1975	2.62
March	1975	8.31
April	1975	5.36
May	1975	8.08
June	1975	6.99
July	1975	6.55
August	1975	21.50

During months of low runoff, the monthly sewage flow may be as much as 50 percent of the estimated monthly runoff. However, during periods of high runoff, the monthly sewage flow may be as little as 2 percent of the estimated runoff value. During low-flow months the daily sewage treatment plant flow is about 757 m^3 (200,000 gal.). The $7Q_2$ is 812 m^3 da^{-1}, and the $7Q_{10}$ is 420 m^3 da^{-1}. Thus, during low-flow periods, the sewage discharge may equal or exceed the natural stream flow.

Table 26. MANITOWOC RIVER RUNOFF FOR WATER YEARS 1974 AND 1975.
(cm)

Month	Year	Runoff
October	1973	0.61
November	1973	0.99
December	1973	1.52
January	1974	1.14
February	1974	0.94
March	1974	7.47
April	1974	7.01
May	1974	2.39
June	1974	2.54
July	1974	0.66
August	1974	0.30
September	1974	0.15
October	1974	0.20
November	1974	0.33
December	1974	0.47
January	1975	0.30
February	1975	0.20
March	1975	4.46
April	1975	6.32
May	1975	2.19
June	1975	0.93
July	1975	0.32
August	1975	0.61
September	1975	1.26

WATER QUALITY

Station Locations

Three stations were selected on Spring Creek for the collection of grab samples. Samples were collected in a plastic bucket from the surface, and then transferred to plastic bottles for transport.

Station I was at the Main Street bridge in Brillion (Figure 8). The stream is 10 - 25 cm deep and 6 - 7 m wide, with a sandy bottom. The

Table 27. BRILLION SEWAGE DISCHARGE AND ESTIMATED SPRING CREEK RUNOFF. JUNE 1974 - JUNE 1975.

Month		Discharge X 10^4 m^3	Estimated runoff X 10^4 m^3	Ratio of sewage to runoff
June	1974	4.597	79.5	.06
July		3.074	20.7	.15
August		2.710	9.4	.29
September		2.341	4.7	.50
October		2.575	6.3	.41
November		2.358	10.3	.23
December		2.431	14.7	.17
January	1975	2.715	9.4	.29
February		2.185	6.3	.35
March		4.241	139.6	.03
April		4.142	197.8	.02
May		3.825	68.5	.06
June		3.243	29.1	.11

location is upstream from the sewage treatment plant, but receives urban and agricultural runoff.

Station II was in Spring Creek at Wolfschmidt Road. The stream enters the marsh immediately downstream from the station. The stream is about 10 m wide and about 1 - 1.5 m deep with a sludge deposit on the bottom. A small channel 2 - 3 m wide and 1 m deep enters Spring Creek 20 m above this station. The channel carries the effluent from the Brillion sewage treatment plant, located some 300 m away.

Station III was located on the open channel about 1900 m below the upper part of Brillion Marsh. The channel is 10 - 15 m wide and 1 - 1.3 m deep. Station III has an organic bottom along the banks but, in midstream, the bottom is mineral matter.

Samples of effluent from the Brillion sewage treatment plant were collected from the effluent pipe

Long-Term Studies

Samples were collected from June 1974 through August 1975. The results of the analyses are given for each station and also for the Brillion sewage treatment plant effluent in Appendix F, Tables F-1 thru F-4. The mean values of the determinations for each parameter at Stations I, II and III are given in Table 28. Also shown on this table is the percent reduction as the water passes through the marsh from Station II to Station III.

The impact of the treatment plant effluent on the water quality of Spring Creek can be seen by comparing the water quality of Station I with Station II. BOD, COD, orthophosphate, total phosphorus, and coliform bacteria all show significant increases. Conductivity and total solids are lower, indicating dilution of dissolved solids in the stream by wastewater.

The impact of the marsh on water quality is shown by the percent reduction column. The most dramatic decrease was in BOD (80.1%) and total coliforms (86.2%). Significant decreases also occurred in turbidity (43.5%), suspended solids (29.1%) and nitrate (51.3%). Reductions in total phosphorus (13.4%), orthophosphate (6.4%), and conductivity (7.7%) also occurred. There was a 34% increase in dissolved solids which caused an 8.5% increase in total solids.

Table 28. MEAN VALUES[a] FROM LONG TERM STUDIES AT STATIONS I, II, III.

Parameter	Station I	Station II	Station III	% Reduction
BOD	5.9	26.9	5.35	80.1
COD	30.5	106	59.7	43.7
Orthophosphate	1.27	3.13	2.93	6.4
Total phosphorus	1.28	3.43	2.97	13.4
Conductivity (umho)	1540	1065	983	7.7
Turbidity (JTU)	26	20	11.3	43.5
Nitrate	1.78	1.17	0.57	51.3
Coliform (log col 100 ml^{-1})	4.76	5.54	4.68	86.2
pH	7.91	7.81	7.42	
Total solids	955	707	767	-8.5
Suspended solids	154	127	90	29.1
Dissolved solids	801	580	677	-16.7

[a] All values are mg l^{-1} unless otherwise indicated in parentheses.

Intensive Study

A three-day intensive study of water quality in Brillion Marsh was made on August 19 - 22, 1974. The purpose of the investigation was to determine the nature and extent of daily variations in parameter concentrations. Starting at noon on August 19th, the samples were collected every four hours until noon, August 22. Samples were collected at Stations I, II, and III. The results of the samples are graphed in Appendix F, Figures F-1 to F-12.

The flow of the Brillion sewage treatment plant and the flow of Spring Creek at Station I during this period are given in Table 29.

Table 29. BRILLION SEWAGE DISCHARGE AND SPRING CREEK STREAMFLOW DURING AUGUST 19 - AUGUST 22, 1974.

Date	Brillion sewage treatment plant discharge	Stream flow in Spring Creek at Station I
August 19, 1974	1070 m^3 da^{-1}	3350 m^3 da^{-1}
August 20, 1974	1000 m^3 da^{-1}	2860 m^3 da^{-1}
August 21, 1974	1000 m^3 da^{-1}	2450 m^3 da^{-1}
August 22, 1974	945 m^3 da^{-1}	2350 m^3 da^{-1}

PRIMARY PRODUCTION AND PHOSPHORUS

Primary Production

Shoots were harvested from the experimental quadrats (Table 30) in Brillion Marsh on July 1, and October 8, 1974, and again on June 19, August 5, and October 7, 1975. Control quadrats were harvested only in October each year. There was generally less growth in both the control and experimental quadrats in 1975 than in 1974 (Table 30). Less growth in 1975 may be a result of climatological variation. There was also generally less total tissue removed from the experimental *Typha* and *Sparganium* plots than from the controls. In the artificial marsh basins at Seymour, the total harvest of *Scirpus* tissue was not diminished by frequent harvesting.

Decreased productivity with harvesting in a natural marsh was also recorded by Hanseter (1975) and is probably typical of natural marsh systems. It can also be noted (Table 30) that the experimental quadrats (multiple harvests) from the effluent end of the marsh produced only about 40% as much standing crop as their control plots. Experimental quadrats on the receiving or upstream end of the marsh produced about 80% as much tissue as their control. There was only a slight difference between control plots. This seems to indicate some sort of limiting factor or lack of reserves in the plants at the downstream end of the marsh.

Table 30. PLANT TISSUE HARVESTED FROM BRILLION MARSH.
(g dw m^{-2})

Receiving end of marsh

		1974			1975			
Quadrat	Treatment	July 1	Oct. 8	Total	June 19	Aug. 5	Oct. 7	Total
1	Experimental	561	314	875	263	429	11	703
2		950	483	1433	243	423	31	697
1c	Control		1072	1072			924	924
2c			1382	1382			1071	1071

Effluent end of marsh

		1974			1975			
Quadrat	Treatment	July 1	Oct. 8	Total	June 19	Aug. 5	Oct. 7	Total
3	Experimental	306	373	679	218	324	6	458
4		291	267	558	137	174	2	313
3c	Control		1168	1168			763	763
4c			1665	1665			1481	1481

Phosphorus

Content in Plant Tissue --

On June 19, 1975, undisturbed control plots were harvested. The old tissue remaining standing from 1974 was separated from the new shoots and the tissue was analyzed for phosphorus content. In the *Typha*, so little phosphorus remained in the old stalks that it could not be detected by the method employed (Table 31). The old *Sparganium* shoots in quadrat 3 contained a small amount of phosphorus. The new 1975 shoots, however, contained 0.05 - 0.09% phosphorus, so that this single, early season harvest removed 0.20 - 0.30 g P m^{-2}. Thus, old plant tissue contains no phosphorus and in spite of a large standing crop, a winter or early spring harvest of tissue would remove little or no phosphorus.

Removal by Harvesting --

By multiple harvesting, the average phosphorus content of the plant tissue was maintained at about 0.125%, while that of the control plants harvested once at the end of the season was only about 0.058% phosphorus (Table 31). There was no apparent difference between the phosphorus content of plants from the upstream and the downstream ends of the marsh.

The amount of phosphorus removed from the control quadrats averaged about 0.6 g m^{-2} (Table 33), and because there was little difference in standing crops, there was little or no difference between

Table 31. CONTRIBUTION OF OLD AND NEW SHOOTS TO HARVESTABLE BIOMASS AND PHOSPHORUS REMOVAL FROM BRILLION MARSH.
(g m^{-2})

Quadrat	Species	Tissue	Dry Weight	% Phosphorus	Phosphorus
1	*Typha*	Old	839	0.00	0.00
		New	287	0.09	0.26
2	*Typha*	Old	801	0.00	0.00
2		New	288	0.07	0.20
3	*Sparganium*	Old	189	0.04	0.06
3		New	243	0.09	0.22
4	*Typha*	Old	212	0.00	0.00
4		New	558	0.05	0.30

Table 32. CONCENTRATION OF PHOSPHORUS IN HARVESTED SHOOTS FROM BRILLION MARSH.
(% P)

Receiving end of marsh		1974		1975		
Quadrat	Treatment	July 1	Oct. 8	June 19	Aug. 5	Oct. 7
1	Experimental	0.254	0.064	0.095	0.158	0.100
2		0.094	0.084	0.091	0.137	0.093
1c	Control		0.054			0.052
2c			0.048			0.067
Effluent end of marsh						
Quadrat	Treatment	July 1	Oct. 8	June 19	Aug. 5	Oct. 7
3	Experimental	0.304	0.110	0.119	0.169	0.093
4		0.122	0.080	0.078	0.114	0.114
3c	Control		0.058			0.074
4c			0.050			0.067

phosphorus removed from the receiving and effluent ends of the marsh. In the multi-harvested experimental plots, at the receiving end of the marsh, there was about twice as much phosphorus removed (0.83 - 162 g P m^{-2}) as from the control plots (Table 33). At the effluent end of the marsh, however, there was about 40% more phosphorus removed from the experimental plots in 1974 but 30% less in 1975. This, again, reflects the apparent lack of reserve of some unknown limiting factor at the effluent end of the marsh.

In spite of previous findings, it was thought that it might be possible to remove a significant portion of the phosphorus from the marsh system by harvesting the plants. If an average of 1 g P m^{-2} could be removed from the system by two or more harvests during the growing season, only 1.56×10^3 kg of phosphorus would be removed from Brillion Marsh. That is only 6.5% of the estimated influx. This minor reduction would be at a very high cost to wildlife using the system. After the first early summer harvest, only 10 - 30 % as much standing crop was present at any time in the harvested quadrats as in the unharvested control plots. Thus, valuable wildlife cover would be removed and machinery used for harvesting would disturb nesting birds. In addition, it was noted that in one experimental quadrat (number 4) the _Typha_ had been largely replaced by _Spraganium_ in 1975. Similar changes in species composition were recorded by Hanseter (1975).

Mass Balance --

If a marsh is to be regarded as an alternative to traditional wastewater treatment processes, it must be capable not only of reducing BOD and killing pathogens, but it must also provide a mechanism for removing mineral nutrients (i.e., phosphorus). Water quality data indicated that there was usually a significant reduction in phosphorus concentration between Stations II and III. Exceptions were recorded, however, and it was known that the marsh was receiving additional phosphorus from non-point agricultural and recreational sources via surface run-off and other tributaries. Thus, an attempt was made to estimate the mass balance of phosphorus in and out of the Brillion Marsh. Values obtained in this study have been expressed as concentrations. Physical constraints

Table 33. REMOVAL OF PHOSPHORUS FROM BRILLION MARSH BY HARVESTING OF PLANT SHOOTS.
(g P m^{-2})

Receiving end of marsh

Quadrat	Treatment	1974 July 1	1974 Oct. 8	1974 Total	1975 June 19	1975 Aug. 5	1975 Oct. 7	1975 Total
1	Experimental	1.42	0.20	1.62	0.25	0.67	0.01	0.93
2		0.89	0.41	1.30	0.22	0.58	0.03	0.83
1c	Control		0.58	0.58			0.48	0.48
2c			0.66	0.66			0.56	0.56

Effluent end of marsh

Quadrat	Treatment	1974 July 1	1974 Oct. 8	1974 Total	1975 June 19	1975 Aug. 5	1975 Oct. 7	1975 Total
3	Experimental	0.93	0.41	1.34	0.15	0.55	0.01	0.77
4		0.36	0.21	0.57	0.11	0.20	0.002	0.31
3c	Control		0.56	0.56			0.57	0.57
4c			0.83	0.83			0.99	0.99

of the channels prevented stream flow measurements anywhere but Station I. It was not possible to measure to the mass flux of water through the marsh system.

An estimate of the mass flux can be made using the average monthly discharge of the Manitowoc River at Manitowoc, Wisconsin. For the period June 1974, through May 1975, this was 18.1 cm for the drainage basin; about an average year. The average phosphorus concentration during this period at each station was: Station I: 0.88 mg l^{-1}; Station II: 3.65 mg l^{-1}; Station III: 1.78 mg l^{-1}.

Station II is assumed to be representative of the 31.2 km^2 drainage basin of Spring Creek entering the marsh and Station I representative of the remaining 18.7 m^2 drainage basin of the marsh study area (Figure 7). With an annual runoff of 5.67×10^6 m^3 into the marsh from Spring Creek, a total of 20.7×10^3 kg of phosphorus entered the marsh through Spring Creek. An additional 3.40×10^6 m^3 of runoff entered from the rest of the drainage basin, carrying with it 2.99×10^3 kg of phosphorus.

Drainage from the marsh will be presumed to be equal to the runoff into it. Precipitation over the marsh is probably cancelled by evapotranspiration from the marsh. Total runoff would be 9.07×10^6 m^3 with 16.1×10^3 kg P.

Total input of phosphorus to the marsh was 23.7×10^3 kg and output was 16.1×10^3 kg. A reduction of 32 percent is noted. However, the method of approximation is fairly crude in terms of estimating the volumes of water. The data should, perhaps, be interpreted as meaning only that the output is on the same order of magnitude as the input. This was also the conclusion reached by Lee, Bently and Amundson (1969) in their study of natural Wisconsin marshes. The marsh does tend to store phosphorus during the summer. Phosphorus is slowly released from the plants and sediments during the fall and winter when flows are low but concentrations are high. A large slug of phosphorus passes from the marsh during spring runoff.

Precipitation Into Sediments --

On August 5, 1975, a series of sediments cores was taken from Brillion Marsh to determine if there was any precipitation of phosphorus into the sediments. The phosphorus concentration in the organic marsh sediments was very uniform and ranged from 1.1 - 2.4 mg P (g dw sediments)$^{-1}$ (Figure 9). There was no difference between the upstream and downstream ends of the marsh. Cores taken from Spring Creek channel in the City of Brillion and especially from the effluent channel of the sewage treatment plant contained up to 20.6 mg P (g dw sediments)$^{-1}$. Over 9 mg per gram were also found in the bottom of Deer Creek Run, a small tributary receiving runoff from dairy farms and a golf course. It must be concluded, then, that some, perhaps a major, portion of the phosphorus which had been assumed to be entering the marsh was, in fact, being removed by some nonbiological precipitation process in the stream channel. Some of the phosphorus may have been

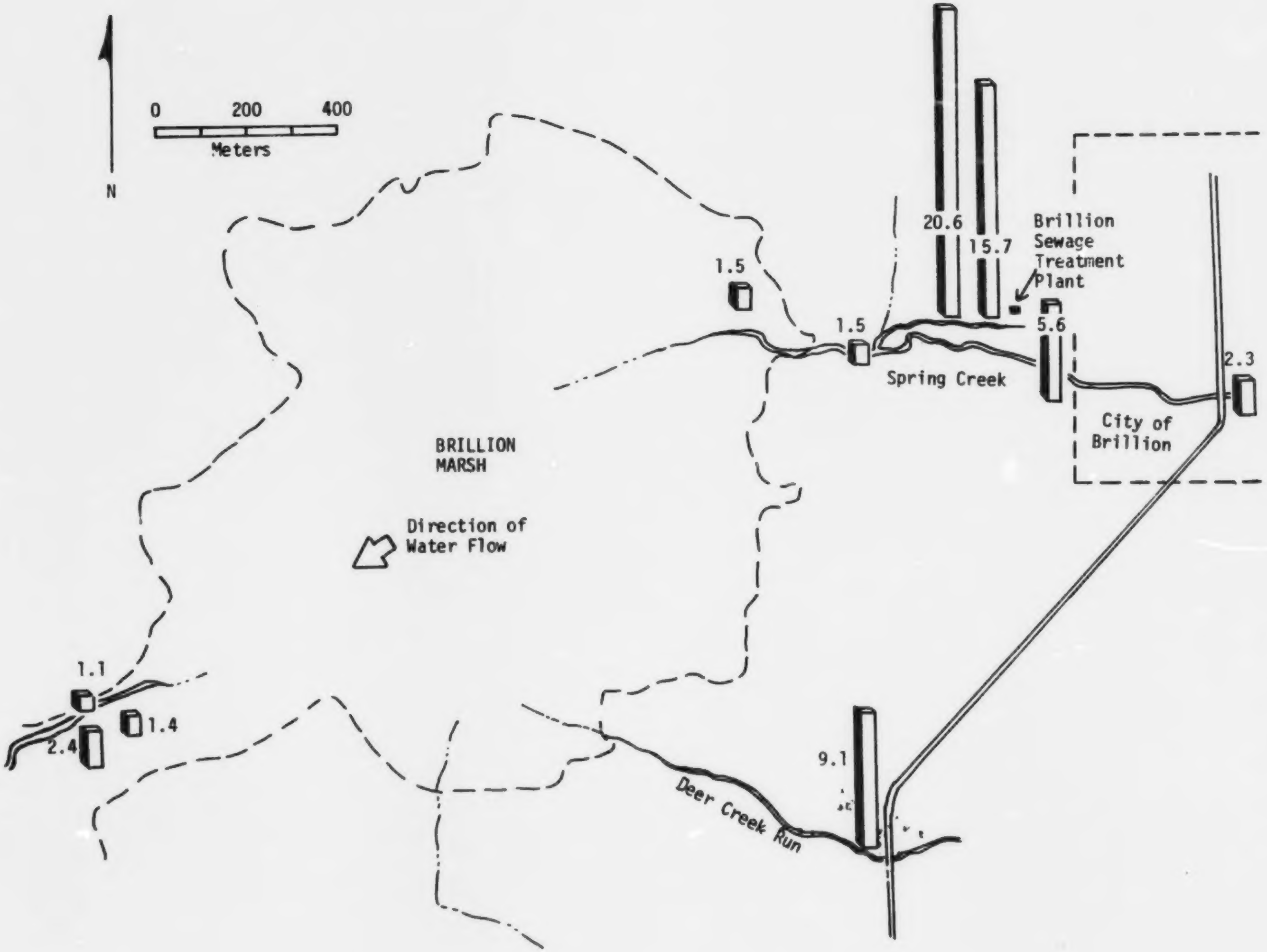


Figure 9. Available Phosphorus in Surface Sediments in Brillion Marsh.
(mg P g^{-1} dry weight sediment)

removed by adsorption onto clay and silt from non-point runoff while another portion may have precipitated with carbonates. This is not to suggest that the aquatic plants played no role in the precipitation process. Wetzel (1969) demonstrated that aquatic macrophytes play a very significant role in precipitation of phosphorus in hard water situations such as in Spring Creek at Brillion. A large stand of submerged plants was present in Deer Creek Run and almost the entire length of the receiving stream and 200 m of Spring Creek above Station II were lined with *Sparganium* and *Typha*.

SECTION XII

REFERENCES CITED AND SELECTED BIBLIOGRAPHY

REFERENCES CITED

American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater (13th ed.) Washington, D.C. 874 p.

Association Official Agricultural Chemists (AOAC). 1960. Methods of Analysis. Assoc. Off. Agric. Chem. Washington, D.C. 832 p.

Hanseter, R.H. 1975. Recovery, Productivity, and Phosphorus Content of Selected Marsh Plants after Repeated Cuttings. MST Thesis University of Wisconsin - Oshkosh 81 p.

Lee, G.F., E. Bentley, and R. Amundson. 1969. Effect of Marshes on Water Quality. Water Chemistry Laboratory, Madison, Wis. mimeo 25 p.

Olsen, S.R. and L.A. Dean. 1965. Phosphorus. In: Methods of Soil Analysis Part 2. C.A. Black (ed.). Amer. Soc. of Agric. Madison, Wi. 1042 p.

Wetzel, R. 1969. Factors Influencing Photosynthesis and Excretion of Dissolved Organic Matter by Aquatic Macrophytes in Hardwater Lakes. Verh. Internat. Verein. Limnol. 17: 72-85.

SELECTED BIBLIOGRAPHY

Allen, H.L. 1969. Primary Productivity, Chemo-organotrophy and Nutritional Interactions of Epiphytic Algae and Bacteria on Macrophytes in the Littoral of a Lake. Ph.D. thesis. 186 p.

Althaus, H. 1966. Biological Wastewater Treatment with Bulrushes. G.W.F. 107(18): 486-488.

American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater (13th ed.) Washington, D.C. 874 p.

Association Official Agricultural Chemists (AOAC). 1960. Methods of Analysis. Assoc. Off. Agric. Chem. Washington, D.C. 832 p.

Association of Aquatic Vascular Plant Biologists (AAVPB) 1974. Newsletter No. 7. (Annotated Bibliography) 60 p.

Bagnall, L.O., T.W. Casselman, J.W. Kesterson, J.F. Easley, R.E. Hellwing, 1971. Aquatic Forage Processing in Florida. ASAE Paper No. 71-536: 1-21.

Bourn, W.S. 1932. Ecological and Physiological Studies on Certain Aquatic Angiosperms. Boyce Thompson Institute for Plant Research, Inc., Contributions 4: 425-496.

Boyd, C.E. 1967. Some Aspects of Aquatic Plant Ecology In: Symposium on Reservoir Fishing Resources. University of Georgia Press: Athens, Ga. 114-129.

Boyd, C.E. 1968. Fresh Water Plants: A Potential Source of Protein. Econ. Bot. 22: 359-368.

Boyd, C.E. 1969. The Nutritive Value of Three Species of Water Weeds. Econ. Bot. 23: 123-127.

Boyd, C.E. 1970. Chemical Analysis of Some Vascular Plants. Archiv. Hydrobiol. 67: 78-85.

Boyd, C.E. 1970. The Dynamics of Dry Matter and Chemical Substances in a *Juncus effusus* Population. Amer. Midl. Nat. 86 (1): 28-45.

Boyd, C.E. 1970. Losses of Mineral Nutrients During Decomposition of *Typha latifolia*. Archiv. fur Hydrobiol. 66(4): 511-517.

Boyd, C.E. 1970. Vascular Aquatic Plants for Mineral Nutrient Removal from Polluted Waters. Econ. Bot. 24(1): 95-103.

Boyd, C.E. 1971. Further Studies on the Productivity, Nutrient and Pigment Relationships in *Typha latifolia* Populations. Bull. Torr. Bot. Club 98(3): 144-150.

Boyd, C.E. 1971. The Limnological Role of Aquatic Macrophytes and Their Relationship to Resevoir Management. Reservoir Fisheries and Limnology No. 8. 153-166.

Boyd, C.E. 1971. Production, Mineral Accumulation and Pigment Concentrations in *Typha latifolia* & *Scirpus Americanus*. Ecol. 51(2): 285-290.

Boyd, C.E. 1971. Variation in the Elemental Content of *Eichornia crassipes*. Hydrobiologia 38(3-4): 409-414.

Boyd, C.E. 1972. Production and Chemical Composition of *Saururus cernuus* L. at Sites of Different Fertility. Ecology 53(5): 927-932.

Boyd, C.E. and R. Blackburn. 1970. Seasonal Changes in the Proximate Composition of Some Aquatic Weeds. Hyacinth Control Journal 8: 42-44.

Boyd, C.E. and L.W. Hess. 1970. Factors Influencing Production and Mineral Nutrient Levels in *Typha latifolia*. Ecology 51: 2.

Boyd, C.E. and J.M. Poiisini. 1972. Relationships Between Cell-wall Fractions, Nitrogen, and Standing Crop in Aquatic Macrophytes. Ecology 53(3): 484-488.

Boyd, C.E. and D.H. Vickers. 1971. Relationships Between Production, Nutrient Accumulation, and Chlorophyll Synthesis in an *Eleocharis quadrangulata* Population. Can. Journ. Bot. 49(6): 883-888.

Burk, C.J., *et.al*. 1973. Partial Recovery of Vegetation in a Pollution-Damaged Marsh. Water Resources Research Center Project Completion Report. University of Massachusetts-Amherst. 27 p.

Burkhart, K.W. 1975. Dirty Water in the Bulrushes. The New Republic. June 14, 1975. 16-19.

Council of Environmental Quality (CEQ). 1974. Evaluation of Municipal Sewage Treatment Alternatives. A final report prepared for CEQ and US EPA, Contract CEQ 316. US Gov. Print. Off. 181 p.

Czerwenda, W. and K. Seidel. 1965. New Methods of Groundwater Enrichment in Krefeld. G.W.F. 106(30): 828-833.

Dean, R.V. 1968. Ultimate Disposal of Wastewater Concentrates to the Environment. Environ. Sci. & Technol. 2: 1079-1086.

Duursma, E.K. 1967. The Mobility of Compounds in Sediments in Relation to Exchange Between Bottom and Supernatant Water, In: Chemical Environment in the Aquatic Habitat, Golterman and Clymo (eds.) Inter. Biol. Year. Symp. Proc. Amsterdam. Oct. 1966. 288-296.

Dykyjova, D. 1969. Contact Diagrams as Help Methods for Comparative Biometry, Allometry, and Production Analysis of *Phragmites*. (Kontaktdiagramme Als Hilfsmethods Fur Verfleidhende Biometrie, Allometrie Und Produktionsanalyse Von *Phragmites*-Okotypen) Rev. Roum. Biol.-Zoologie. Tome 14, No. 2 107-119.

Dykyjova, D. (ed.) 1970. Productivity of Terrestial Ecosystem Production Processes. IBP/ PT-PP Report No. 1 Praha. 233 p.

Dykyjova, D. and D. Hradecka. 1973. Productivity of Reed Bed Stands in Relation to the Ecotype, Microclimate and Trophic Conditions of the Habitat. Pol. Arch. Hydrobiol. 20(1): 111-119.

Dykyjova, D. and S. Husak. 1973. The Influence of Summer Cutting on the Regeneration of Reed. Ecosystem Study on Wetland Biome in Czechoslovakia. Czechosl. IBP/PT-PP Report No. 3. 242-250.

Dykyjova, D. and J.P. Ondok. 1973. Biometry and the Productive Stand Structure of Coenoses of Sparganium erectum L. Preslia, Praha. 45: 19-30.

Dykyjova, D. and J. Kvet. 1970. Comparison of Biomass Production in Reedswamp Communities Growing in South Bohemia and South Moravia. In: Productivity of Terrestial Ecosystem Production Processes. D. Dykyjova (ed.) PT/PP IBP Report No. 1 71-78.

Dykyjova, D., P.J. Ondok and D. Hradrecka. 1972. Growth Rate and Development of the Root/Shoot Ratio in Reedswamp Macrophytes Grown in Winter Hydroponic Cultures. Folia Geobot. Phytotax., Praha 7: 259-268.

Dykyjova, D., J.P. Ondok and K. Priban. 1970. Seasonal Changes in Productivity and Vertical Structures of Reed Stands (Phragmites communis Trin.). Photosynthetica 4(4): 280-287.

Environmental Protection Agency (EPA). 1971. Methods for Chemical Analysis of Water and Wastes. #16020. US Gov. Print. Off.: Washington, D.C. 312 p.

Fiala, K., D. Dykyjova, J. Kvet and J. Svoboda. 1968. Methods of Assessing Rhizome and Root Production in Reed Bed Stands. In: IBP Symposium: Methods of Productivy Studies in Root Systems and Rhizosphere Organisms. Leningrad, Aug. 28-Sept. 12, 1968. 36-47.

Fitzgerald, G.P. 1968. Nutrient Sources for Algae and Aquatic Weeds. Univ. Wisconsin-Madison, Water Chemistry Laboratory #WP 00297. 16 p.

Fitzgerald, G.P. 1969. Field and Laboratory Evaluations of Bioassays for Nitrogen and Phosphorus with Algae and Aquatic Weeds. Limnol. Oceanogr. 14(2): 206-212.

Fitzgerald, G.P. and G.F. Lee. 1971. Use of Tests for Limiting of Surplus Nutrients to Evaluate Sources of Nitrogen and Phosphorus for Algae and Aquatic Weeds. Project Completion Report Univ. Wis-Madison. 27 p.

Forsberg, C. 1959. Quantitative Sampling of Subaquatic Vegetation. Oikos 10(2): 233-240.

Frink, C.R. 1969. Chemical and Mineralogical Characteristics of Eutrophic Lake Sediments. Soil Sci. Soc. Amer. Proc. 33: 369-372.

Frink, C.R. 1969. Fractionation of Phosphorus in Lake Sediments: Analytical Evaluation. Soil Sci. Soc. Amer. Proc. 33: 326-328.

Gahler, A.R. 1969. Field Studies on Sediment-Water-Algal Nutrient Interchange Processes and Water Quality of Upper Klamath and Agency Lakes. Working Paper No. 66. EPA Corvallis, Ore. 49 p.

Gahler, A.R. and W.D. Sanville. 1971. Characterization of Lake Sediments and Evaluation of Sediment-Water Nutrient Interchange Mechanisms in the Upper Klamath Lake System. Paper No. 66. EPA Corvallis, Ore. 49 p.

Gates, W.E. and J.A. Borchardt. 1964. Nitrogen and Phosphorus Extraction from Domestic Wastewater Treatment Plant Effluents by Controlled Algal Culture. Journ. Water Poll. Cont. Fed. 36(4): 443-462.

Gerloff, G. 1973. Plant Analysis for Nutrient Assay of Natural Waters. EPA-R1-73-001 U.S. Gov. Print. Off.: Washington, D.C. 67 p.

Gerloff, G.C. and P.H. Krombholz. 1966. Tissue Analysis as a Measure of Nutrient Availability for the Growth of Angiosperm Aquatic Plants. Limnol. Oceanogr. 11: 529-537.

Golterman, H.L. 1967. Influence of the Mud on the Chemistry of Water in Relation to Productivity. In: Chemical Environment in Aquatic Habitat, Golterman and Clymo (eds.) Int. Biol. Year. Symp. Proc. Amsterdam. Oct. 1966.

Golterman, H.L., C.C. Bakels and J. Jakobs-Mogelin. 1969. Availability of Mud Phosphates for the Growth of Algae. Verh. Internat. Verein. Limnol. 17: 467-479.

Gosselt, D.R. and W.E. Norris. 1971. Relationship Between Nutrient Availability and Content of N and P in Tissue of the Aquatic Macrophyte, Eichornia crossipes (Mart) Solms. Hydrobiologia 38: 15-28.

Goulder, R. and D.J. Boatman. 1970. Evidence that Nitrogen Supply Influences the Distribution of a Freshwater Macrophyte, Ceratophyllum Demersum. Journ. Ecol. 59(3): 783-791.

Gowen, D. 1971. The Disposal of Agricultural Waste. Part 1. The Problem Perspective. Effluent and Water Treatment Journ. June: 303-308.

Hajek, B.F. and R.E. Wildung. 1969. Chemical Characterization of Pond Sediments. Northwest Sci. 43: 130-134.

Haller, W.T. and D.L. Sutton. 1973. Effect of pH and High Phosphorus Concentrations on Growth of Water Hyacinth. Hyacinth Control Journal. 11: 59-61.

Hannon, H.H. and T.C. Dorris. 1970. Succession of a Macrophyte Community in a Constant Temperature River. Limnol. Oceanogr. 15(2): 442-453.

Hanseter, R.H. 1975. Recovery, Productivity and Phosphorus Content of Selected Marsh Plants after Repeated Cuttings. M.S.T. Thesis, Univ. of Wis.-Oshkosh. 81 p.

Harper, H.J. and H.A. Daniel. 1934. Chemical Composition of Certain Aquatic Plants. Bot. Gaz. 96: 186-189.

Harriman, N.A. 1969. Autecology of Rooted Aquatic Plants in Lake Butte des Morts, Wisconsin. Wis. Dept. Nat. Res. Proj. W0141-R-5. No. 305. 6 p.

Hayes, F.R., J.A. McCarter, M.L. Comeron and D.A. Livingstone. 1952. On the Kinetics of Phosphorus Exchange in Lakes. J. Ecol. 40(1): 202-216.

Hejny, S. (ed.) 1973. Ecosystem Study on Wetland Biome in Czechoslovakia. IBP/PT-PP Report No. 3: Trebon. 256 p.

Hejny, S. and S. Husak. 1973. Macrophyte Vegetation of the Nesyt Fishpond. In: Littoral of the Nesyt Fishpond. J. Kvet, (ed.). Studie CSAV 15, Academia, Praha. 49-54.

Hetesa, J., K. Hudec and S. Husak. 1973. Lednice Fishponds and Their Investigation. In: Littoral of the Nesyt Fishpond. Kvet (ed.). Studie CSAV 15, Academia, Praha. 11-15.

Holm, L.G., L.W. Weldon and R.D. Blackburn. 1969. Aquatic Weeds. Science 166: 699-709.

Husak, S. 1973. Destructive Control of Stands of Phragmites communis and Typha angustifolia and its Effects on Shoot Production Followed for Three Seasons. In: Littoral of the Nesyt Fishpond. J. Kvet (ed.) Studie CSAV 15, Academia, Praha. 89-91.

Husak, S. and S. Hejny. 1973. Marginal Plant Communities of the Nesyt Fishpond (South Moravia). Pol Arch. Hydrobiol. 20(3): 461-466.

Husak, S. and P. Smid. 1973. Vegetation Map of the Neyst Fishpond Littoral. In: Littoral of the Neyst Fishpond. J. Kvet (ed.). Studie CSAV 15, Academia, Praha. 59-62.

Hutchinson, G.E. 1970. The Chemical Ecology of Three Species of Myriophyllum (Angiospermae, Haloragaceae). Limnol. Oceanogr. 15(1): 1-5.

de Jong, J. 1975. Bulrush and Reed Ponds. Int. Conf. on Biol. Water Qual. Improv. Altern. Philadelphia. March 3-5, 1975. 12 p.

Kaul, V. and K. Voss. 1970. Production of Some Macrophytes of Sprinagar Lakes. In: Productivity Problems of Fresh Waters. Prelim. Papers for UNESCO-IBP Symp. Kazimierz Dolny, Poland 6-12. 195-208.

Keup, L.E. 1967. Phosphorus in Flowing Waters. Water Res. 2: 373-386.

Kickuth, R. 1969. Higher Water Plants and Water Purification: Ecochemical Effects of Higher Plants and their Functions in Water Purification. Schriftenreihe der Vereiningung Duetscher Gerwasserschutz EV-VDG no. 19.

Kickuth, R. 1969. The Bulrush Eats Phenol. Deutscher Forschungsdienst 14(14): 1-2.

Kiefer, W. 1968. Biological Waste Water Treatment with Plants. Ulmschau No. 7 210 p.

Koegel, R.G., H.D. Bruhn and D.F. Livermore. 1972. Improving Surface Water Conditions Through Control and Disposal of Aquatic Vegetation: Phase I. Processing Aquatic Vegetation for Improved Handling and Disposal or Utilization. Water Resource Center, Univ. of Wis.-Madison Tech. Report WRR B-018-Wis. 55 p.

Koegel, R.G., D.F. Livermore, H.D. Bruhn and P. Bautz. 1973. Improving Surface Water Conditions Through Control and Disposal of Aquatic Vegetation. Phase II. Water Resource Center, Univ. Wis.-Madison Tech. Report WSI-WRC 73-07 38 p.

Kohler, V.A., H. Vollrath and E. Beisl. 1971. The Distribution, the Phytosociological Composition, and the Ecology of Vascular Macrophytes in the Moasach River System Near Munich. Arch. Hydrobiol. 69(3): 333-366.

Kok, T. 1974. The Purification of Sewage from a Camping Site with the Aid of a Bulrush Pond. H_2O 7(24): 536-544.

Koridon, M. 1971. The Influence of Bulrushes on the Dying of *E. coli*. and the Breakdown of Phenol. H_2O 4(13): 296-298.

Kormondy, E.J. 1968. Weight Loss of Cellulose and Aquatic Macrophytes in a Carolina Bay. Limnol. Oceanogr. 13(3): 522-524.

Kvet, J. 1973. Mineral Nutrients in Shoots of Reed *Phragmites communis* Trin. Pol. Arch. Hydrobiol. 20(1): 137-147.

Kvet, J. (ed.). 1973. Littoral of the Nesyt Fishpond. Studie CSAV 15, Academia, Praha. 1.

Lee, G.F. 1970. Factors Affecting the Transfer of Materials Between Water and Sediments. Literature Review No. 1. Eutroph. Inform. Progm., Univ. Wis. Water Resources Center, Madison, Wi. 50 p.

Lee, G.F., E. Bentley and R. Amundson. 1969. Effect of Marshes on Water Quality. Water Chemistry Laboratory, Madison, WI. mimeo 25 p.

Lind, C.T. and F. Cottam. 1969. The Submerged Aquatics of University Bay: A Study in Eutrophication. Am. Mid. Nat. 81(2): 353-369.

Linde, A.F. 1969. Techniques for Wetland Management. Wis. Dept. Nat. Res. Rept. 156 p.

Linde, A.F. 1971. Vegetation Studies on Rock River Marshes in the Chemical Treatment Zone. Wis. Dept. Nat. Res. Proj. Comp. Rept. 13 p.

Livermore, D.F. and W.E. Wunderlich. 1969. Mechanical Removal of Organic Production from Waterways. In: Eutrophication: Causes, Consequences, Correctives. Nat. Acad. Sci. Washington, D.C. 494-517.

McCombie, A.M. and W. Ivanka. 1971. Ecology of Aquatic Vascular Plants in Southern Ontario Impoundments. Weed Sci. 19(3): 225-228.

McDonnell, A.J. and D.W. Weeter. 19 . Respiration of Aquatic Macrophytes in Eutrophic Ecosystems. Penn. State U. Res. Publ. No. 67. 74 p.

McKee, G.D., C.R. Parrish, C.R. Birth, K.M. Mckenthun and L.E. Keup. 1969. Sediment-water Nutrient Relationships. Natl. Field. Inc. Center, Cinn., Ohio. 149-154.

McNaughton, S.J. 1966. Ecotype Function in the *Typha* Community-Type. Ecol. Monog. 36: 297-325.

McRoy, C.P. and R.J. Barsdate. 1970. Phosphate Absorption in Eel Grass. Limnol. Oceanogr. 15(1): 6-13.

Modlin, R.F. 1970. Aquatic Plant Survey of Milwaukee River Watershed Lakes. Wi. D.N.R. Research Rept. No. 52.

Moore, E. 1915. The *Potomagetons* in Relation to Pond Culture. Bull. U.S. Bur. Fish. 33: 249-291.

Morozov, N.V. 1969. The Role of Higher Plants in the Self-purification of Oil-polluted Rivers. Gidrebiologicheski johurnal (Translated Hydrobiological Journal 5(4): 37-42).

Mulligan, H.E. and A. Baranowski. 1969. Growth of Phytoplankton and Vascular Aquatic Plants at Different Nutrient Levels. Verh. Int. Verein. Limno. 17: 802-811.

Nichols, S.A. 1971. Distribution and Control of Macrophyte Biomass in Lake Wingra. Water Resource Center, University of Wis.-Madison. IBP Proj. Completion Report. 111 p.

Olsen, S.R. and L.A. Dean. 1965. Phosphorus In: Black, C.A. (ed.). Methods of Soil Analysis Part 2. Am. Soc. of Agr. Madison, Wi. 1042 p.

Oota, Y. and T. Tsudzuki. 1971. Resemblance of Growth Substances to Metal Chelators with Respect to Their Actions on Duckweed Growth. Plant & Cell Physiol. 12: 619-631.

Ondok, J.P. 1969. Die Probleme Der Anwendung Der Wachstums-Analyse Auf Forschungen Von *Phragmites comminis* Trin. (The problems of the application of the growth analysis of the investigation of *Phragmites communis* Trin.) Hydrobiologia 10: 87-95.

Ondok, J.P. 1968. Measurement of Leaf Area in *Phragmites communis* Trin. Photosynthetica 2(1): 25-30.

Ondok, J.P. 1972. Vegetative Propagation in *Scirpus lacustris* L., Biologia Plantarum (Praha) 14(3): 213-218.

Ondok, J.P. 1973. Some Basic Concepts of Modelling Freshwater Littoral Ecosystems with Respect to Radiation Regime of a Pure *Phragmites* Stand. Pol. Arch. Hydrobiol. 20(1): 101-109.

Owens, M. and R.W. Edwards. 1960. The Effects of Plants on River Conditions. I. Summer Crops and Estimates of Net Productivity of Macrophytes in a Chalk Stream. Jour. Ecol. 48: 151-160.

Peltier, W.H. and E.B. Welch. 1970. Factors Affecting Growth of Rooted Aquatic Plants in a Resevoir. Weed Science 18: 7-9.

Penfound, W.T. 1956. Primary Production of Vascular Aquatic Plants. Limnol. Oceanog. 1: 92-101.

Rickett, H.W. 1924. A Quantitative Study of the Larger Aquatic Plants of Green Lake, Wisconsin. Trans. Wis. Acad. Sci. 21: 381-414.

Reimer, D.N. and S.J. Toth. 1968. A Survey of the Chemical Composition of Aquatic Plants in New Jersey. New Jersey Agr. and Exper. Station Bull. 14 p.

Reimer, D.N. and S.J. Toth. 1968. A Survey of the Chemical Composition of *Potamogeton* and *Myriophyllum* in New Jersey Weed Science 17(2): 219-223.

Rogers, H.H. Jr. 1971. Nutrient Removal by Water Hyacinth. Ph.D. Thesis. Auburn Univ. Auburn, Ala.

Ryan, J.B., D.N. Reimer and S.J. Toth. 1972. Effects of Fertilization on Aquatic Plants, Water, and Bottom Sediments. Weed Science 20(5): 482-486.

Scarsbrook, E. and D.E. Davis. 1971. Effect of Sewage on Growth of Five Vascular Species. Hyacinth Control Journal 9: 26-30.

Schmidt, R.L. 1973. Phosphorus Release from Lake Sediments. Project 16010 DUA US EPA, EPA-R3-73-024.

Schomer, H.A. 1934. Photosynthesis of Water Plants at Various Depths in Lakes of Northeastern Wisconsin. Ecology 15: 217-218.

Seidel, K. 1963. Uber Phenolspeicherung and Phenolabbau in Wasserpflanzen. Naturwissenshaften 50: 452.

Seidel, K. 1965. Phenolabbau in Wasser Durch *Scirpus lacustris* L. Wahrend Einer Versuch Dauer von 31 Monaten. Naturwissenshaften 52: 398.

Seidel, K. 1966. Reinigung von Gewass Durch Hohere Pflanzen. Naturwissenschaften 53(12): 289-297.

Seidel, K. 1967. Mixotrophie bei *Scirpus lacustris* L. Naturwissenschaften 54(7): 176-177.

Seidel, K. 1968. Elimination of Dirt and Sludge from Polluted Water Through Higher Plants. Journ. Zivilisationskrankheiten 5: 154-155.

Seidel, K. 1971. Wirkung Hoherer Pflanzen auf Pathogene Keime in Gewassern. Naturwissenschaften 58(4): 150-151.

Seidel, K. 1971. Macrophytes as Functional Elements in the Environment of Man. Hydrobiologia 12: 121-130.

Seidel, K. 1971. Physiologische Leistung von *Alisma Plantago* L. (Froschloffel). Naturwissenschaften 58(3): 151.

Seidel, K. 1972. Exsudat-effekt der Rhizothamnien von *Alnus glutinosa* Gaertner. Naturwissenschaften 59(8): 366-367.

Seidel, K. and R. Kickuth. 1965. Excretion of Phenol in the Phyllosphere of *Scirpus lacustris* L. Naturwissenschaften 52(18): 517-518.

Seidel, K. and R. Kickuth. 1967. Biological Treatment of Phenol-containing Wastewater with Bulrush (*Scirpus lacustris* L.) Wasserwirtschaft-Wassertechnik 17(6): 209-210.

Seidel, K., F. Scheffer, R. Kickuth and E. Schlimme. 1967. Uptake and Metabolism of Organic Materials by the Bulrush. G.W.F. 108(5): 138-139.

Shukla, S., J.K. Syers, J. Williams, D. Armstrong and R. Harris. 1971. Sorption of Inorganic Phosphate by Lake Sediments. Soil Sci. Soci. Amer. Proc. 35: 244-249.

Sloey, W.E. 1969. Aquatic Plant Communities in Lake Butte des Morts, Wisconsin. Phase 2. Effects of Higher Aquatic Plants, Marsh Water, and Marsh Sediments of Phytoplankton. Wis. Dept. Nat. Res. Proj. No. W-141-R-5. 20 p.

Sommers, L., R. Harris, J. Williams, D. Armstrong and J. Syers. 1970. Determination of Total Organic Phosphorus in Lake Sediments. Limnol. Oceanogr. 17: 301-304.

Spiers, J.M. 1948. Summary of Literature on Aquatic Weed Control. Can. Fish Cult. 3(4): 20-32.

Stake, E. 1967. Higher Vegetation and Nitrogen in a Rivulet in Central Sweden. Schweiz. Z. Hydrol. 22: 107-124.

Stake, E. 1968. Higher Vegetation and Phosphorus in a Small Stream in Sweden. Schweiz. Z. Hydrol. 30: 353-373.

Stewart, K.K. 1970. Nutrient Removal Potential of Various Aquatic Plants. Hyacinth Cont. Journ. 8: 34-35.

Straskraba, M. 1968. The Contribution of Higher Plants in the Productivity of Drainage-free Water Basins (Der Anteil der hoheren Pflanzen an der Produktion der Stehended Gewasser). Verh. Internat. Verein. Limnol. 14: 212-230.

Tilstra, J., K. Malueg and C. Powers. 1973. A Study on Disposal of Campground Wastes Adjacent to Waldo Lake, Oregon. Nat. Eutrophi. Res. Prog. 22 p.

Timmer, C. and L. Weldon. 1967. Evapotranspiration and Pollution by Water Hyacinth. Hyacinth Control Journ. 6: 34-37.

Toth, S. and A. Ott. 1970. Characterization of Bottom Sediments: Cation Exchange Capacity and Exchangeable Cation Status. Environ. Sci. Technol. 4: 935-939.

Toth, S., J. Prince and D. Mihkelsen. 1948. Rapid Quantitative Determination of Eight Mineral Elements in Plant Tissue by a Systematic Procedure Involving Use of a Flame Photometer. Soil Sci. 66: 1-4.

Ulehlova, B., S. Husak and J. Dvorak. 1973. Mineral Cycles in Reed Stands of Nesyt Fishpond in Southern Moravia. Pol. Arch. Hydrobiol. 20(1): 121-129.

Van Schreven, D.A. 1971. The Drying Out of a Bulrush Pond During Autumn as a Means of Reducing the Nitrogen Content of the Soil. H_2O 4(17): 382-384.

Van der Valk, A.G. and L.C. Bliss. 1970. Hydrarch Succession and Net Primary Production of Oxbow Lakes in Central Alberta. Can. Journ. Bot. 49(7): 1177-1199.

Watanabe, F.S. and S.R. Olsen. 1962. Colorimetric Determination of Phosphorus in Water Extracts of Soil. Soil Sci. 93: 183-188.

Wentz, D.A. and G.F. Lee. 1969. Sedimentary Phosphorus in Lake Cores: Analytical Procedures. Environ. Sci. Technol. 3: 750-759.

Westlake, D.F. 1968. The Biology of Aquatic Weeds in Relation to their Management. Proc. 9th Brit. Weed Cont. Conf. 372-379.

Wetzel, R.G. 1964. Primary Productivity of Aquatic Macrophytes. Verh. Internat. Verein. Limnol. 15: 426-436.

Wetzel, R.G. 1965. Techniques and Problems of Primary Productivity Measurements in Higher Aquatic Plants and Periphyton. Mem 1st Ital. Idrobiol. 18: 249-267.

Wetzel, R.G. 1969. Factors Influencing Photosynthesis and Excretion of Dissolved Organic Matter by Aquatic Macrophytes in Hard-water Lakes. Verh. Internat. Verein. Limnol. 17: 72-85.

Wetzel, R.G. and B.A. Manny. 1972. Secretion of Dissolved Organic Carbon and Nitrogen by Aquatic Macrophytes. Verh. Internat. Verein. Limnol. 18: 162-170.

Wetzel, R.G. and D.L. McGregor. 1968. Axenic Culture and Nutritional Studies of Aquatic Macrophytes. Amer. Mid. Natl. 80(1): 52-64.

Wildung, R.E. and R.L. Schmidt. 1973. Phosphorus Release From Lake Sediments. Sea-Grant Water Research Lab. Madison. No. 90106. 185 p.

Williams, J., J. Syers, D. Armstrong and R. Harris. 1971. Characterization of inorganic Phosphate in Noncalcareous Lake Sediments. Soil Sci. 35: 556-561.

Williams, J., J. Syers, R. Harris and D. Armstrong. 1971. Fractionation of Inorganic Phosphorus in Calcareous Lake Sediments. Soil Sci. 35: 250-255.

Williams, J., J. Syers, S. Shukla and R. Harris. 1971. Levels of Inorganic and Total Phosphorus in Lake Sediments as Related to Other Sediment Parameters. Environ. Sci. Technol. 5: 1113-1120.

Williford, J.W., J.A. McKeag and W.R. Johnston. 1971. Field Techniques for Removing Nitrates from Drainage Water. ASAE. 14(1): 167-171.

Wilson, D.O. 1970. Phosphate Nutrition of the Aquatic Angiosperm, Myriophyllum exalbescens Fern. Limnol. Oceanogr. 17(4): 612-615.

Yount, J.L. and R.A. Crossman, Jr. 1970. Eutrophication Control by Plant Harvesting. J. Water Poll. Control Fed. 42: 173-183.

SECTION XIII

GLOSSARY

Artificial Marsh - A constructed area containing herbaceous emergent vegetation through which wastewater is permitted to flow. In this case, plastic-lined basins were partially filled with gravel which was used as a substrate.

Effluent - The water flowing out of the experimental basins and the pilot plant. Not to be confused with primary effluent and secondary effluent which are produced by the municipal wastewater treatment plant.

Emergent Vegetation - Grasses, sedges and other herbaceous plants which typically grow in wetlands or natural marshes (see below) and which have a substantial portion of erect tissue extending above the water surface.

Evapotranspiration - Water loss resulting from transpiration via plant leaf surfaces and direct evaporation from other exposed surfaces.

Experimental Basin - The square, plastic-lined basins used in this project.

Influent - The water entering the experimental basins and the pilot plant. In some cases it is wastewater which has received secondary (activated sludge) treatment. In other cases it was wastewater which has received primary treatment only.

Intercalary Meristem - A meristem, removed from the apical meristem, which produces primary tissue; *e.g.*, the zone of cell division at the base of emergent leaves of some marsh plants.

Natural Marsh - An area having free standing water at least part of the year and having a substantial cover of grasses and other herbaceous plants but little or no substantial cover of perennial woody plants. Herein used to refer to the entire ecosystem, including plants, surface and near-surface water and sediments (primarily organic) to the depth of the plant roots.

Pilot Plant - The long, plastic-lined trench used in this project.

Primary Effluent - Wastewater which received primary treatment (only) in the municipal treatment plant.

Propagule - A vegetative propagation unit which may consist of any viable part.

Secondary Effluent - Wastewater which received secondary treatment in the municipal treatment plant.

Shoot - The emergent portion of the plant. In all cases used, this refers to sheathes of leaves only and does not include submergent rhizomes or other woody tissues.

Substrate - The medium into which the roots of the vegetation penetrate.

SECTION XIV

APPENDICES

Page

A. Dye Studies 107

B. Greenhouse Data 115

C. Experimental Basin Data 121

D. Pilot Plant Data 133

E. Data Related to Phosphorus Distribution 154

F. Brillion Marsh Data 156

APPENDIX A

DYE STUDIES

Dye Study I

One gram Rhodamine-B dissolved in 1.2 l water and introduced with influent water on June 14, 1975. At that time, there was approximately 2.5 cm (1 in.) of free-standing water on top of the gravel substrate due to recent rainfalls.

As might be expected, the water moved across the surface along the path of least resistance (Figure A-1). Within ten hours, dye was detected in the effluent. Some dye did penetrate into the gravel as low readings were recorded at 30 and 45 cm in the center basin after only 23 hours. The main flow of water, however, was horizontally over the surface to the area immediately above the outlet, then vertically down to the outlet at 60 cm depth.

Dye Study II

One gram of Rhodamine-B was introduced with influent on July 21, 1975. All flow at that time was below the surface (no surface water). Water collected from small depressions in the gravel indicated that there was little or no flow directly at the surface (Figure A-2). Subsurface flow, however, was nearly uniform indicating that the design was proper. Unfortunately, no dye was ever detected in the effluent. This apparently indicates that the dye was absorbed onto organic materials in the inter-gravel spaces.

Dye Study III

This study was conducted in order to determine the effect of removal of the plywood partitions on the flow patterns in the pilot plant.

Two grams of Rhodamine-B in one 1 of water were introduced on August 13 and sampling was continued until August 25, 1975. Results were virtually identical to those in Study II in that dye reached downstream end after four days, but never was found in the effluent. The flow was apparently uniform throughout the portion of the basin in which dye was detected (Figure A-3).

RHODAMINE-B STUDY I

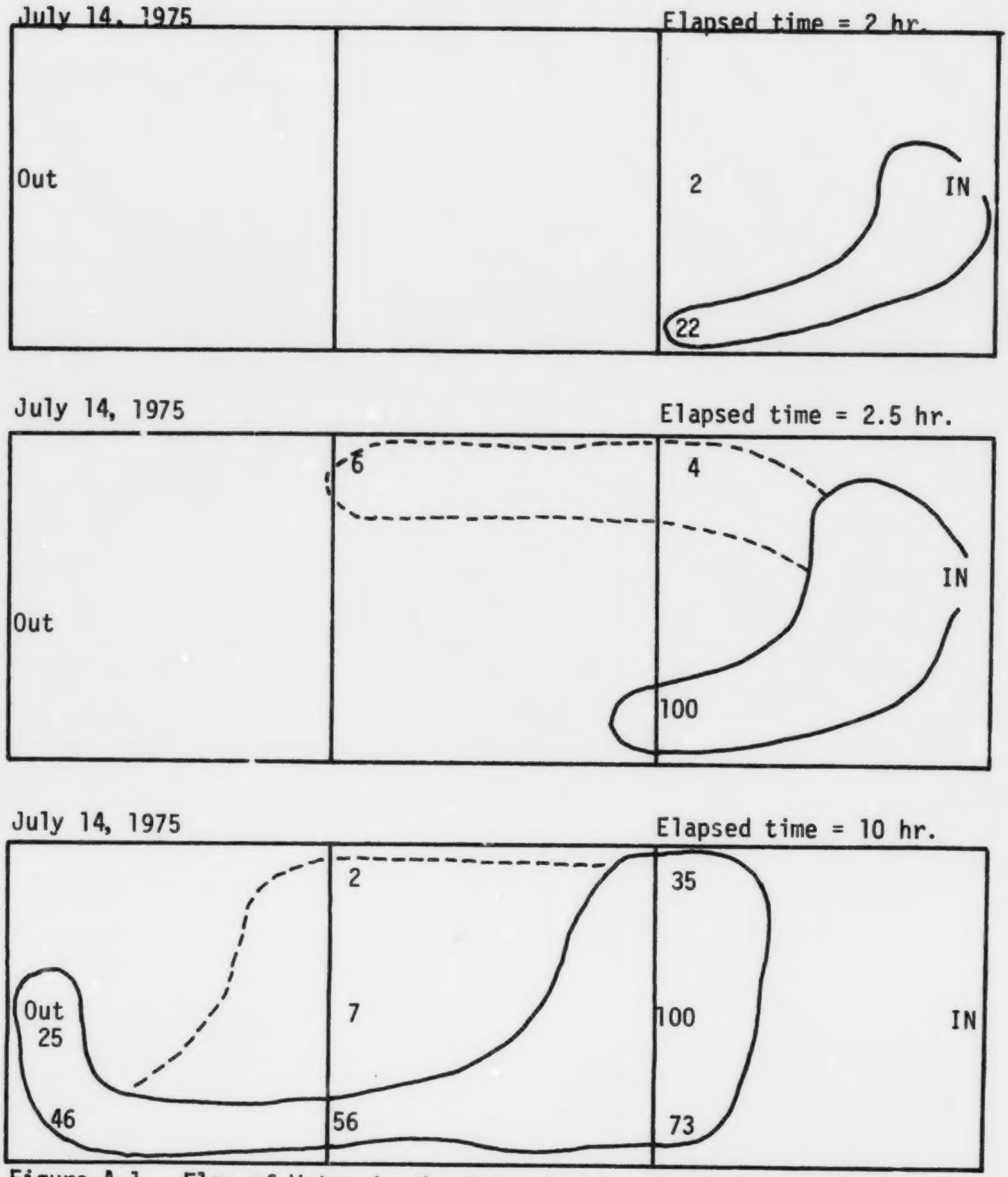
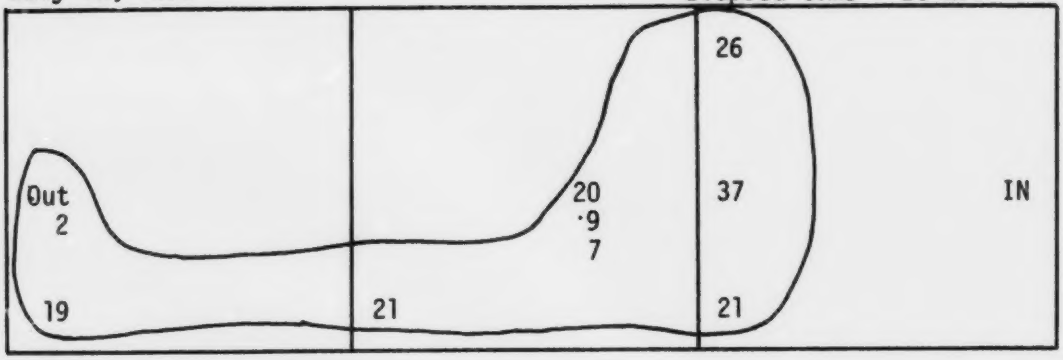


Figure A-1. Flow of Water in the Bulrush Pilot Plant When Water Level was 2.5 cm Above Gravel Substrate. Numbers are Fluorometer Readings. Vertical Series of Numbers Represent Readings at 0, 15 and 60 cm, Respectively.

RHODAMINE-B STUDY I

July 15, 1975 Elapsed time = 23 hr.



July 16, 1975 Elapsed time = 46 hr.

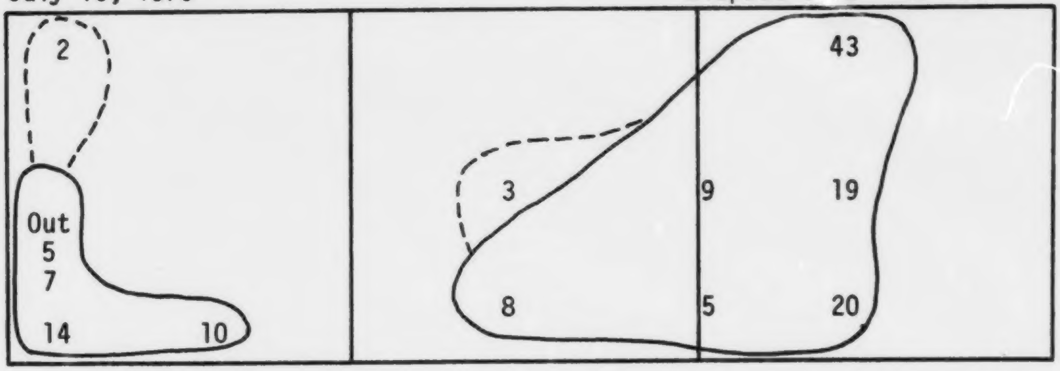


Figure A-1 (continued). Rhodamine-B Study I.

RHODAMINE-B STUDY II

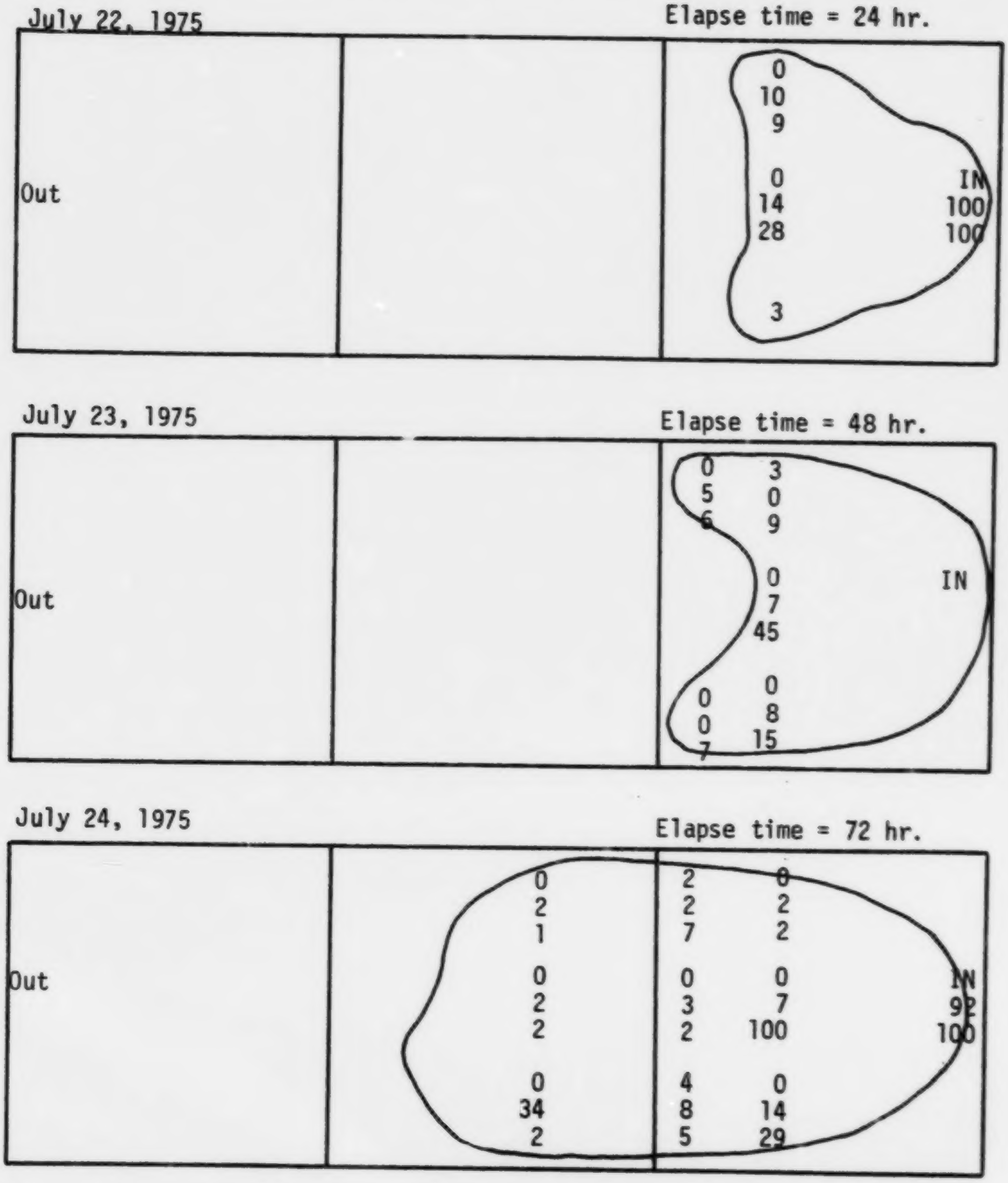


Figure A-2. Flow of Water in Bulrush Pilot Plant When Water Level Was at Gravel Substrate Surface. Numbers are Fluorometer Readings. Vertical Series of Numbers Represent Readings at 0, 15 and 60 cm, Respectively.

RHODAMINE-B STUDY II

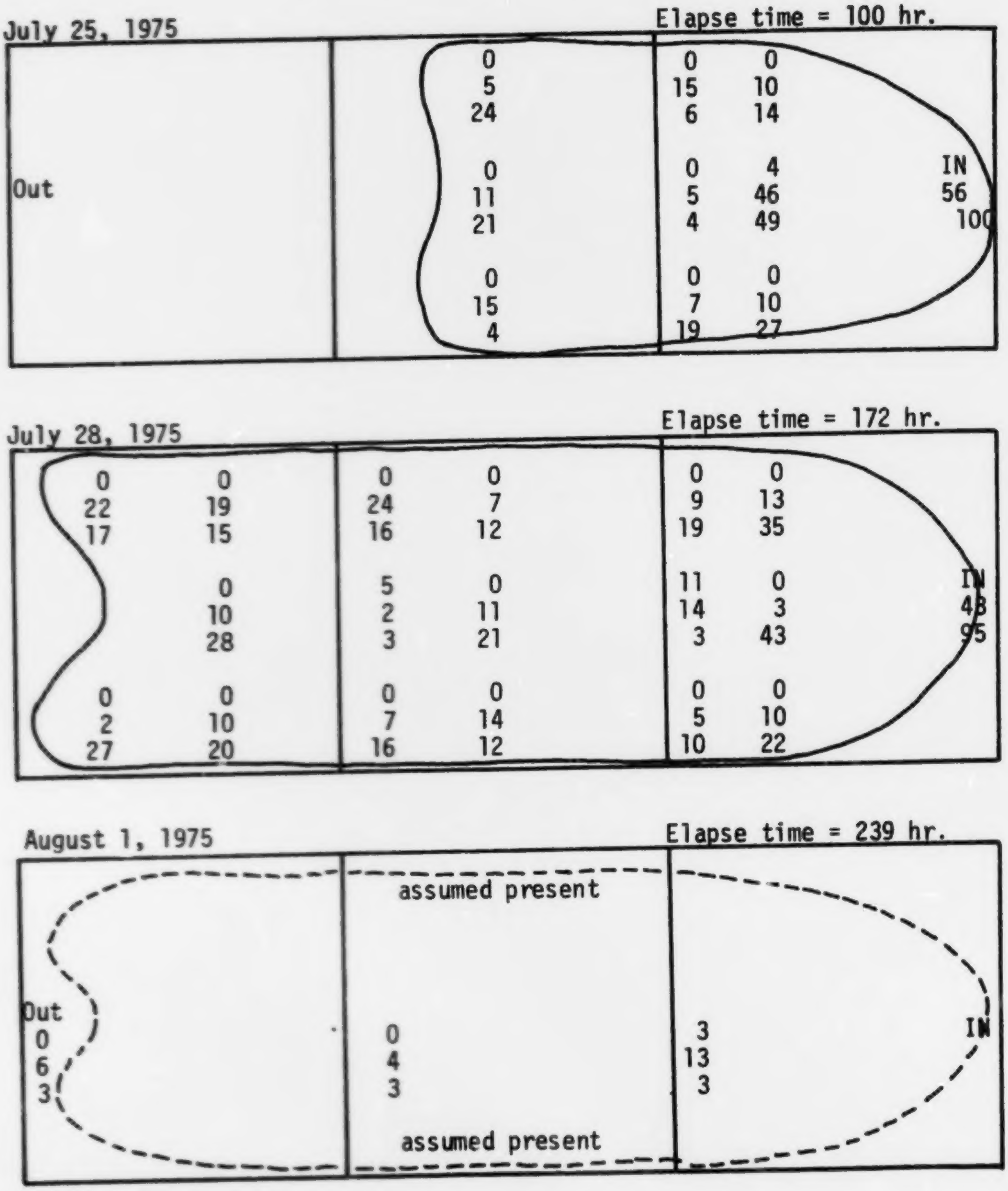


Figure A-2 (continued). Rhodamine-B Study II.

RHODAMINE-B STUDY III

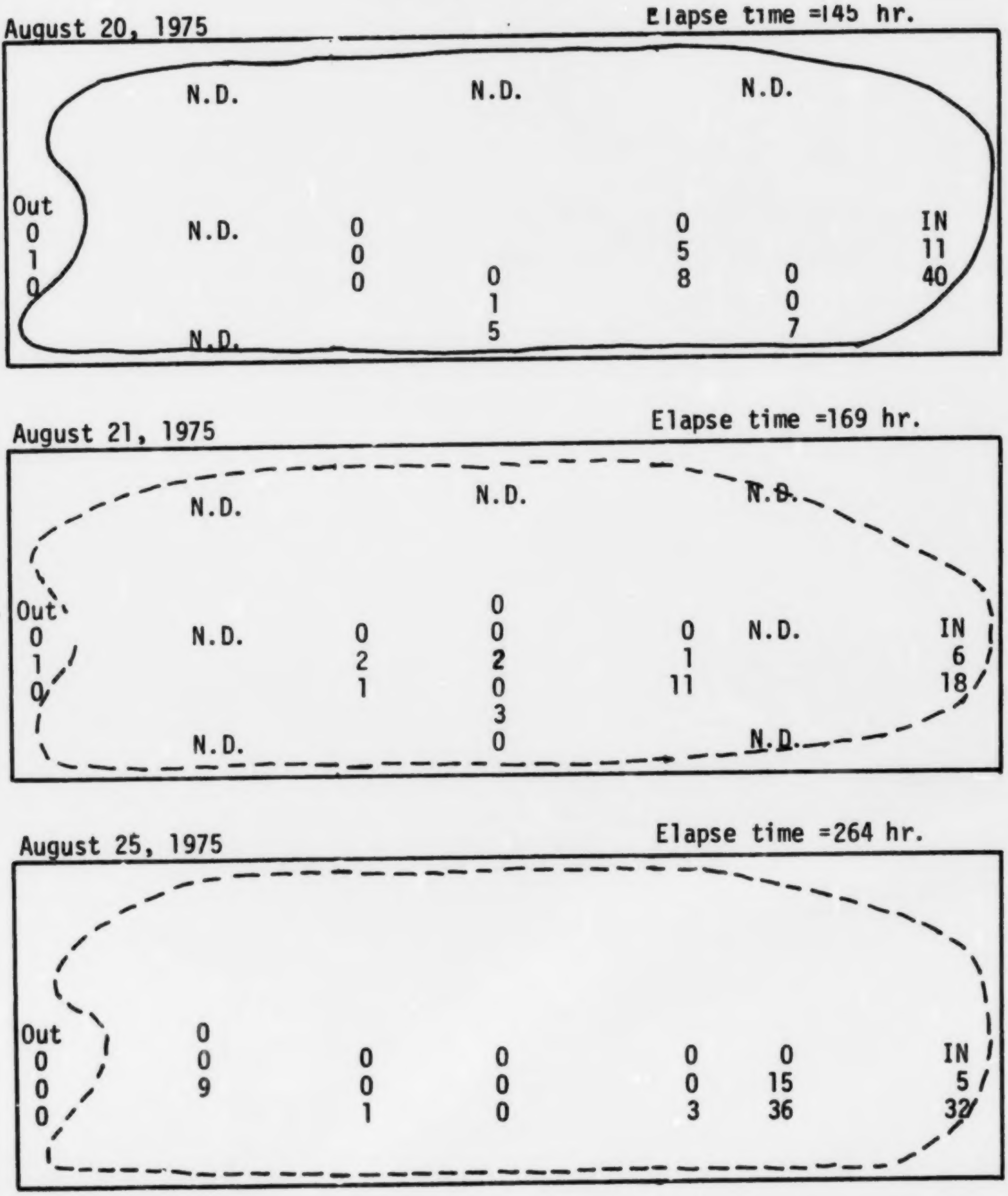
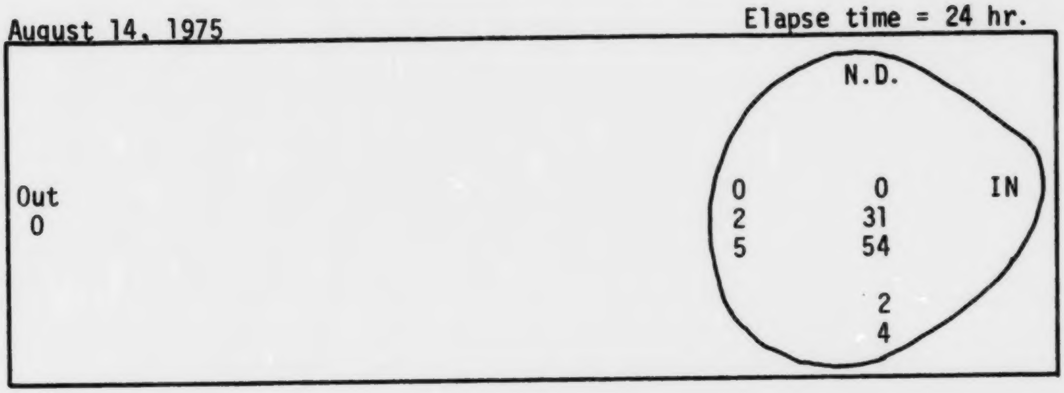


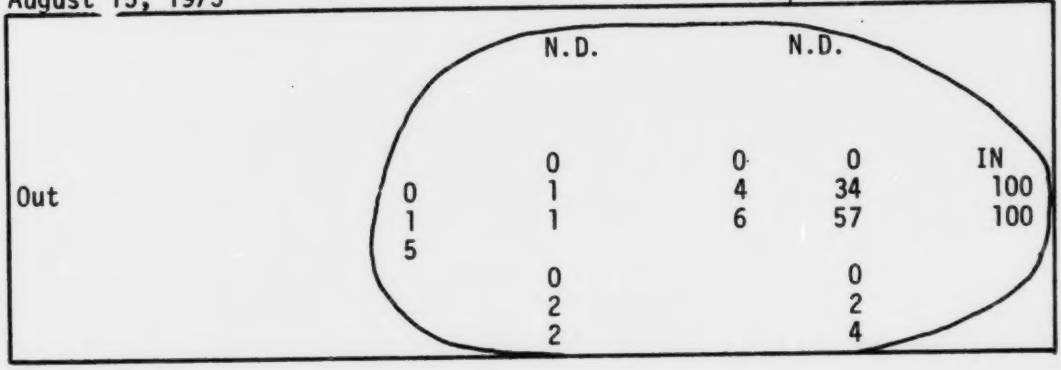
Figure A-3. Flow of Water Through Bulrush Pilot Plant When Outlet was at 60 cm and the Wooden Partitions Had Been Removed. Numbers are Fluorometer Readings a Vertical Series of Numbers Represent Readings at 0, 15, and 60 cm, Respectively.

RHODAMINE-B STUDY III

August 14, 1975 Elapse time = 24 hr.



August 15, 1975 Elapse time = 48 hr.



August 18, 1975 Elapse time = 96 hr.

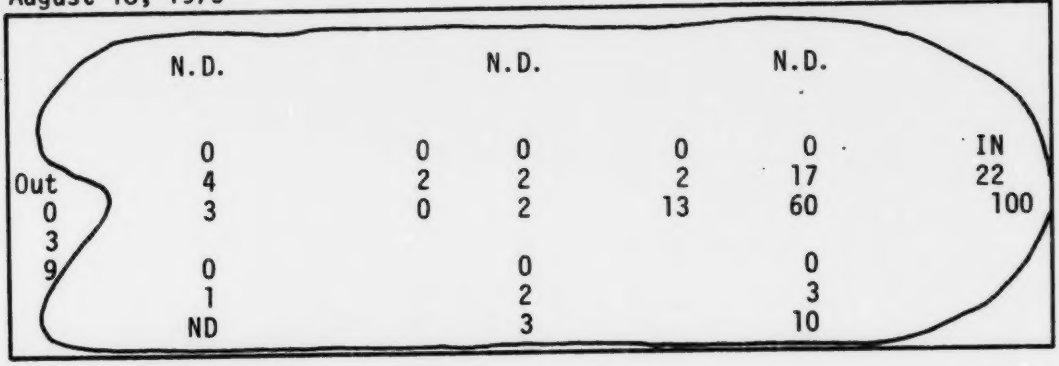


Figure A-3 (continued). Rhodamine-B Study III.

APPENDIX B

GREENHOUSE DATA

Table B-1. WATER BALANCE DATA FOR GREENHOUSE STUDIES. (liters)

	Influent	Total effluent	% evapotranspiration
Five day retention			
Iris	84	30.7	63
Control	84	31.7	62
Hardstem	84	31.7	62
Softstem	84	33.7	60
Softstem	82	34.2	58
Three day retention			
Iris	140	86	38
Control	140	87	37
Hardstem	140	84	40
Softstem	142	91	36
Softstem	142	95	33
One & one-half day retention			
Iris	377	282	26
Control	378	274	28
Hardstem	373	329	12
Softstem	373	343	8
Softstem	378	368	9

Table B-2. EFFECTIVENESS OF GREENHOUSE BEDS IN TREATING PRIMARY EFFLUENT. ONE AND ONE-HALF DAY RETENTION.

	Influent load			Effluent load			%
	mg l^{-1}	liters	g	mg l^{-1}	liters	g	reduction
BOD							
Iris	104	377	39	15	282	4	89
Control	104	378	39	19	274	5	86
Hardstem	104	373	39	11	329	4	90
Softstem	104	373	39	13	343	4	88
Softstem	104	378	39	20	368	7	81
COD							
Iris	125	377	47	84	282	24	49
Control	125	378	47	78	274	22	54
Hardstem	125	373	47	55	329	18	61
Softstem	125	373	47	57	343	20	57
Softstem	125	378	47	90	368	33	29
Orthophosphate							
Iris	1.21	377	0.46	1.68	282	0.47	-3
Control	1.21	378	0.46	1.69	274	0.46	-1
Hardstem	1.21	373	0.45	0.98	329	0.32	28
Softstem	1.21	373	0.45	0.56	343	0.19	57
Softstem	1.21	378	0.46	0.86	368	0.32	30
Total phosphorus							
Iris	2.25	377	0.85	2.09	282	0.59	30
Control	2.25	378	0.85	2.10	274	0.57	32
Hardstem	2.25	373	0.84	1.05	329	0.34	59
Softstem	2.25	373	0.84	0.96	343	0.33	60
Softstem	2.25	378	0.85	1.12	368	0.41	51
Coliform (log col. 100 ml^{-1})							
Iris	3.28	377	5.86	3.38	282	5.82	7
Control	3.28	378	5.86	3.31	274	5.74	22
Hardstem	3.28	373	5.85	3.26	329	5.77	15
Softstem	3.28	373	5.85	3.30	343	5.84	4
Softstem	3.28	378	5.86	3.27	368	5.83	5

Table B-2 (continued). EFFECTIVES OF GREENHOUSE BEDS. ONE AND ONE-HALF DAY RETENTION.

	Influent load			Effluent load			%
	gl^{-1}	liters	g	gl^{-1}	liters	g	reduction
Total solids							
Iris	0.75	377	283	0.83	282	234	17
Control	0.75	378	284	0.78	242	214	24
Hardstem	0.75	373	280	0.82	322	264	5
Softstem	0.75	373	280	0.86	343	295	-5
Softstem	0.75	378	284	0.88	368	324	-14
Suspended solids							
Iris	0.11	377	41	0.09	282	25	39
Control	0.11	378	41	0.07	274	19	54
Hardstem	0.11	373	41	0.10	322	32	22
Softstem	0.11	373	41	0.10	343	34	16
Softstem	0.11	378	41	0.13	368	48	-15
Dissolved solids							
Iris	0.64	377	241	0.74	282	209	13
Control	0.64	378	242	0.71	274	195	19
Hardstem	0.64	373	239	0.72	322	232	2
Softstem	0.64	373	239	0.76	343	261	-9
Softstem	0.64	378	242	0.75	368	276	-14

Table B-3. EFFECTIVENESS OF GREENHOUSE BEDS IN TREATING PRIMARY EFFLUENT. THREE-DAY RETENTION.

	Influent load			Effluent load			%
	mg l^{-1}	liters	g	mg l^{-1}	liters	g	reduction
BOD							
Iris	179	140	25	17.9	86	1.5	94
Control	179	140	25	40.9	87	3.6	86
Hardstem	179	140	25	23.2	84	1.9	92
Softstem	179	142	25	12.1	91	1.1	96
Softstem	179	142	25	13.6	95	1.3	95
COD							
Iris	409	140	57	179	86	15.4	73
Control	409	140	57	163	87	14.2	75
Hardstem	409	140	57	73	84	6.1	89
Softstem	409	142	58	96	91	8.8	85
Softstem	409	142	58	112	95	10.7	82
Orthophosphate							
Iris	4.08	140	0.57	6.1	86	0.53	8
Control	4.08	140	0.57	6.7	87	0.58	2
Hardstem	4.08	140	0.57	4.1	84	0.34	41
Softstem	4.08	142	0.58	2.4	91	0.21	63
Softstem	4.08	142	0.58	3.1	95	0.30	49
Total phosphorus							
Iris	5.51	140	0.77	5.9	86	0.51	34
Control	5.51	140	0.77	9.2	87	0.80	-4
Hardstem	5.51	140	0.77	5.1	84	0.42	45
Softstem	5.51	142	0.78	3.3	91	0.30	62
Softstem	5.51	142	0.78	3.8	95	0.36	54
Coliform (log col. 100 ml^{-1})							
Iris	3.29	140	5.43	3.00	86	4.93	68
Control	3.29	140	5.43	2.79	87	4.72	80
Hardstem	3.29	140	5.43	2.73	84	4.65	83
Softstem	3.29	142	5.44	2.56	91	4.52	88
Softstem	3.29	142	5.44	2.51	95	4.49	89

Table B-3 (continued). EFFECTIVENESS OF GREENHOUSE BEDS. THREE-DAY RETENTION.

	Influent load			Effluent load			%
	mg l^{-1}	liters	g	mg l^{-1}	liters	g	reduction
Total solids							
Iris	1046	140	146	1158	86	100	32
Control	1046	140	146	1085	87	95	35
Hardstem	1046	140	146	1128	84	94	35
Softstem	1046	142	148	1230	91	112	25
Softstem	1046	142	148	1168	95	111	25
Dissolved solids							
Iris	783	140	110	994	86	86	22
Control	783	140	110	944	87	82	22
Hardstem	783	140	110	981	84	82	25
Softstem	783	142	111	1032	91	94	15
Softstem	783	142	111	1003	95	95	14
Suspended solids							
Iris	258	140	36	165	86	14	61
Control	258	140	36	140	87	12	66
Hardstem	258	140	36	133	84	11	69
Softstem	258	142	37	167	91	15	59
Softstem	258	142	37	165	95	16	57

Table B-4. EFFECTIVENESS OF GREENHOUSE BEDS IN TREATING PRIMARY EFFLUENT. FIVE-DAY RETENTION.

	Influent load			Effluent load			%
	mg l^{-1}	liters	g	mg l^{-1}	liters	g	reduction
COD							
Iris	284	84	23.9	90	30.7	2.7	89
Control	284	84	23.9	84	31.7	2.6	89
Hardstem	284	84	23.9	98	31.7	3.1	87
Softstem	284	84	23.9	88	33.7	2.9	87
Softstem	284	82	23.3	135	34.2	4.6	80
BOD							
Iris	250	84	21.0	15	31.7	0.5	98
Control	250	84	21.0	22	31.7	0.7	97
Hardstem	250	84	21.0	19	31.7	0.6	97
Softstem	250	84	21.0	16	33.7	0.5	97
Softstem	250	82	20.5	19	34.2	0.6	97
Orthophosphate							
Iris	6.30	84	0.5	7.35	30.7	0.2	57
Control	6.30	84	0.5	8.02	31.7	0.2	52
Hardstem	6.30	84	0.5	5.42	31.7	0.2	67
Softstem	6.30	84	0.5	3.74	33.7	0.1	76
Softstem	6.30	82	0.5	4.51	34.2	0.2	70
Total phosphorus							
Iris	13.19	84	1.1	7.37	30.7	0.2	80
Control	13.19	84	1.1	8.37	31.7	0.3	76
Hardstem	13.19	84	1.1	5.43	31.7	0.2	83
Softstem	13.19	84	1.1	5.51	33.7	0.2	83
Softstem	13.19	82	1.1	6.54	34.2	0.2	79

APPENDIX C

EXPERIMENTAL BASIN DATA

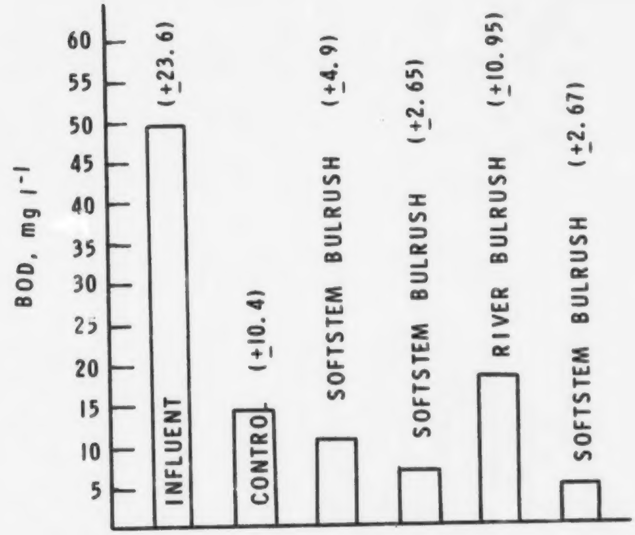


Figure C-1. BOD of Samples Collected Between June 19 and July 31, 1974.

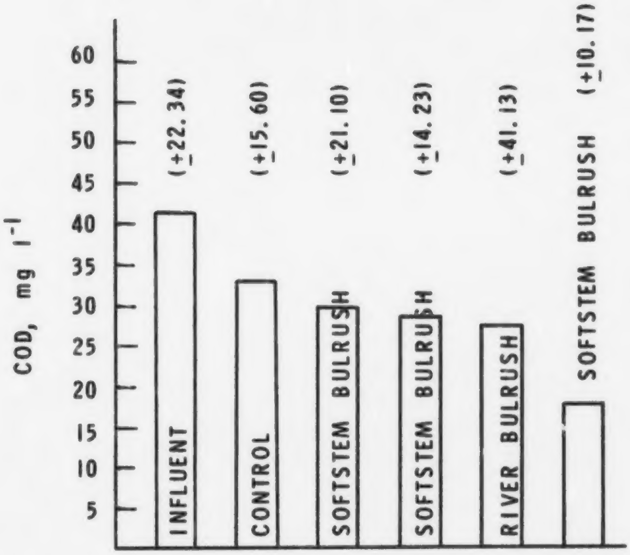


Figure C-2. COD of Samples Collected Between June 19 and July 31, 1974.

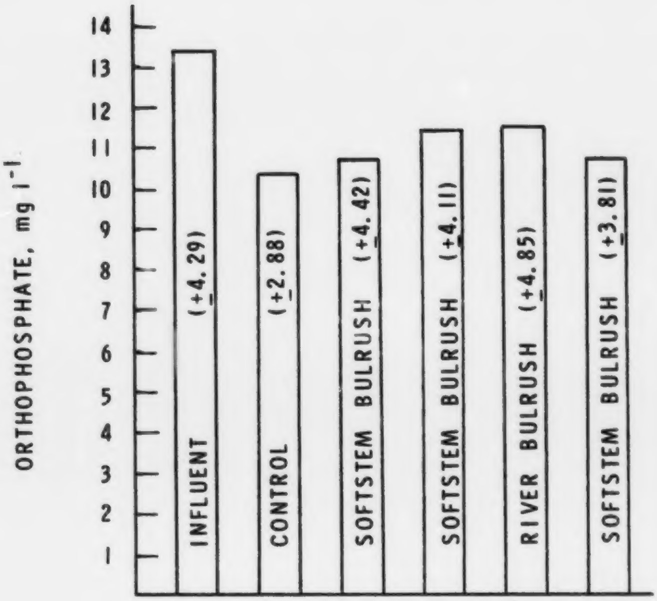


Figure C-3. Orthophosphate Concentrations in Samples Collected Between June 19 and August 31, 1974.

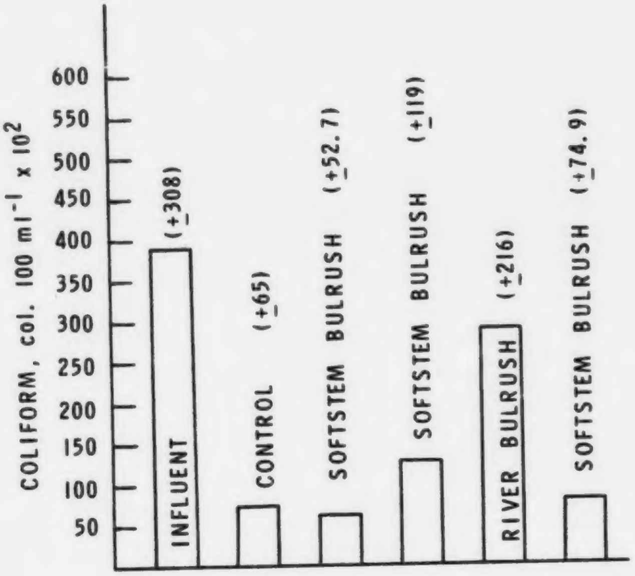


Figure C-4. Coliform Bacteria in Samples Collected Between June 19 and August 31, 1974.

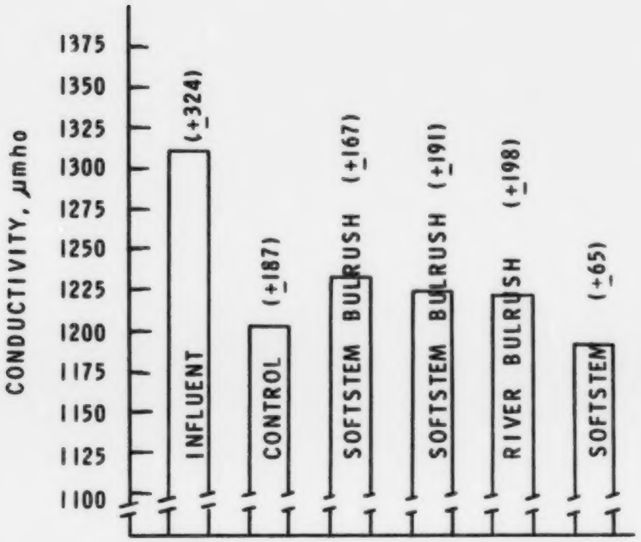


Figure C-5. Conductivity of Samples Collected Between June 19 and August 31, 1974.

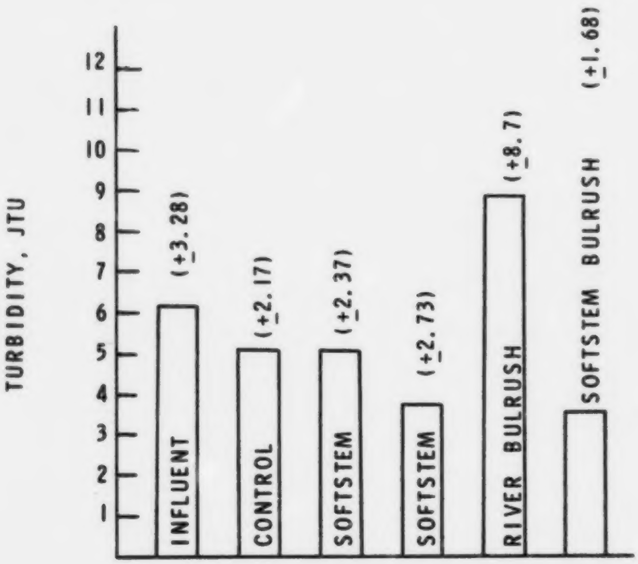


Figure C-6. Turbidity of Samples Collected Between June 19 and August 31, 1974.

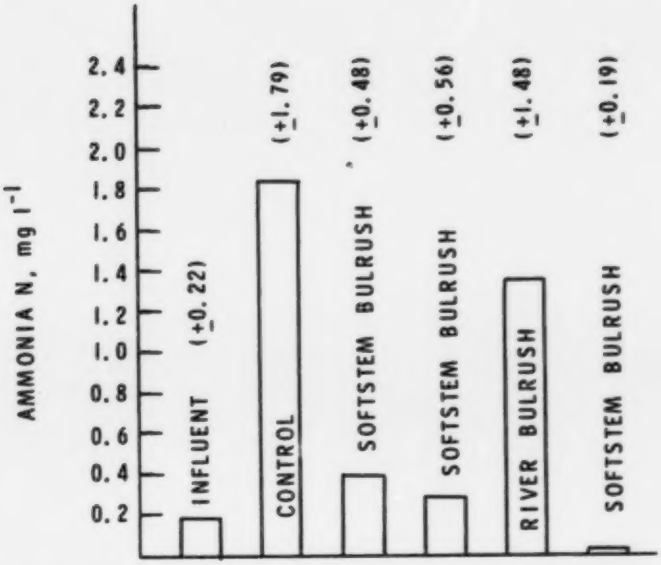


Figure C-7. Ammonia Concentrations in Samples Collected Between June 19 and July 31, 1974.

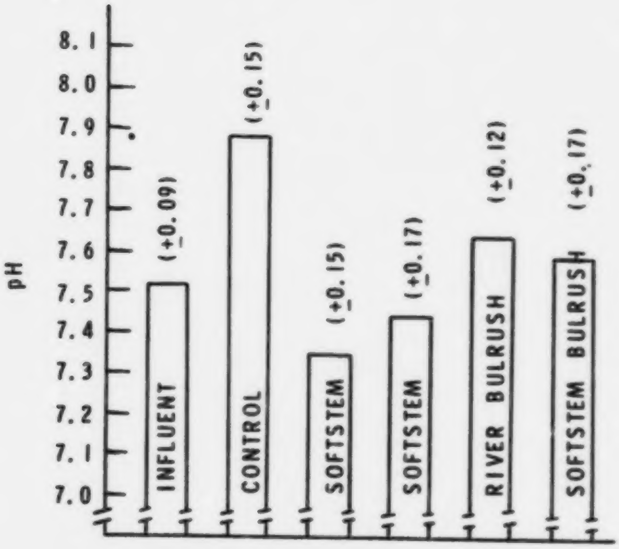


Figure C-8. pH of Samples Collected Between June 19 and August 31, 1974.

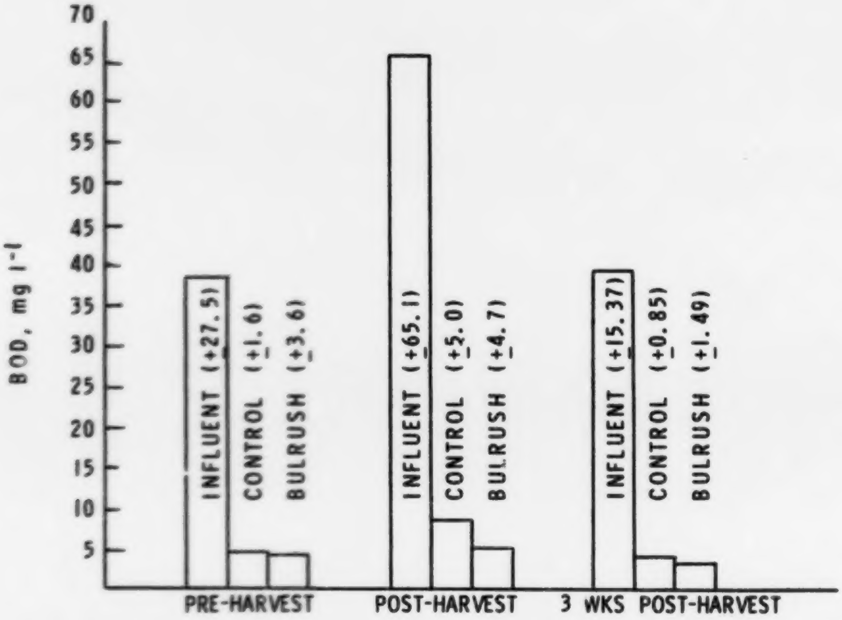
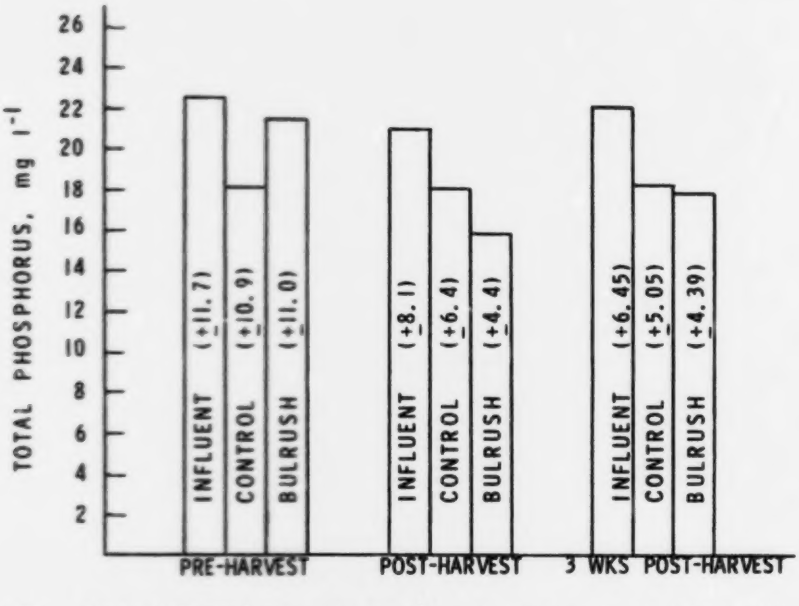


Figure C-9. BOD Reduction by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).



Five C-10. Total Phosphorus Reduction by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).

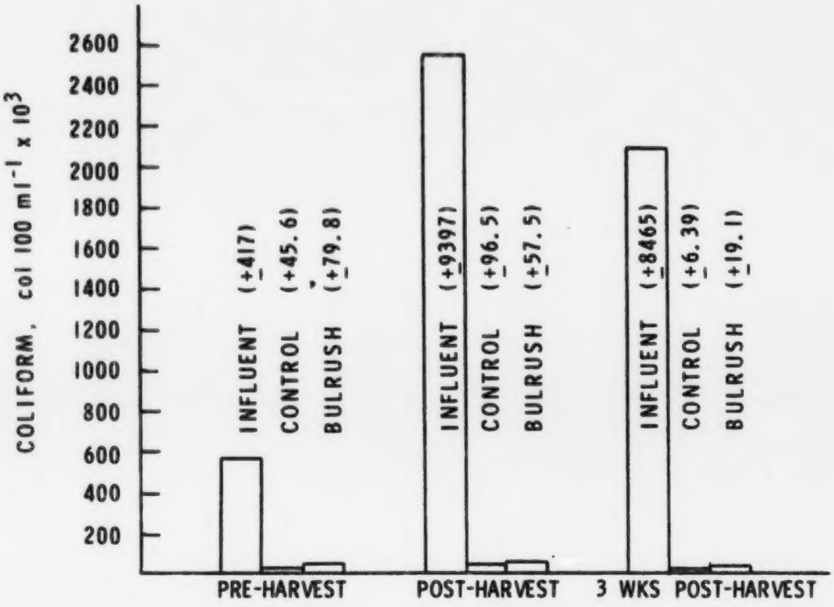


Figure C-11. Coliform Reduction by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).

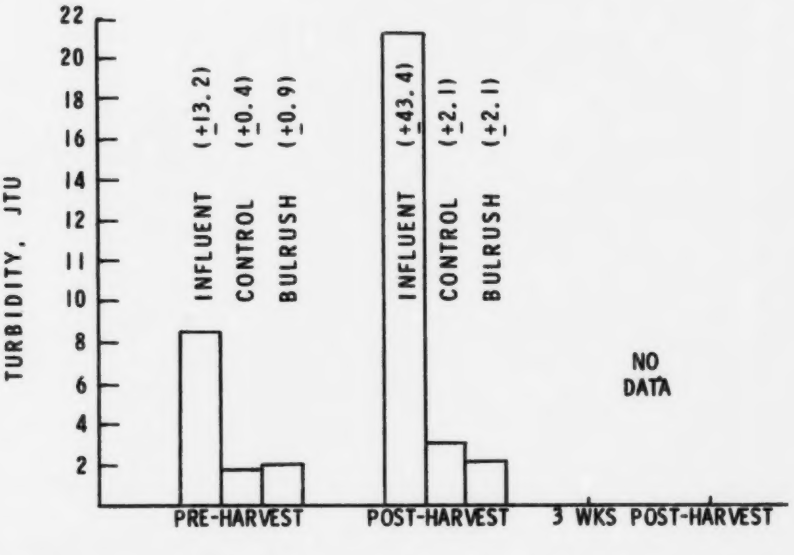


Figure C-12. Turbidity Reduction by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).

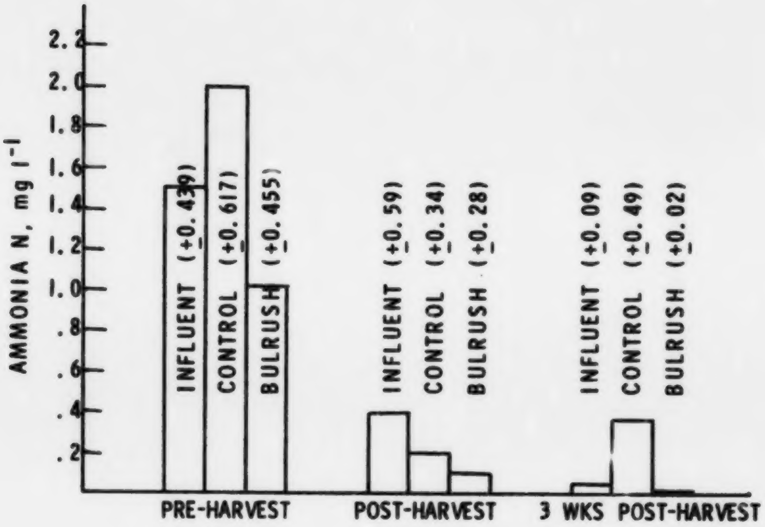


Figure C-13. Ammonia Removal by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).

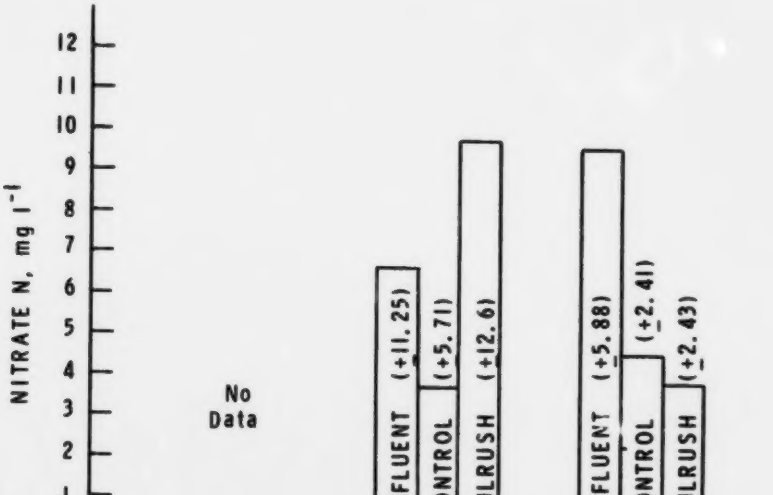


Figure C-14. Nitrate Reduction by Control and Experimental Bulrush Basin During Three Intensive Study Periods (five-hour retention).

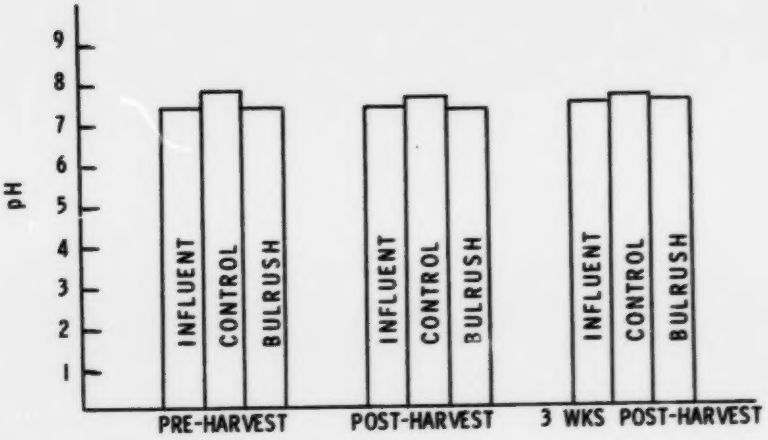


Figure C-15. pH Values of Secondary Effluent, Control Pond Effluent and Experimental Basin Effluent During Three Intensive Study Periods.

Table C-1. AVERAGE VALUES OF VARIOUS PARAMETERS DURING THREE INTENSIVE STUDY PERIODS. SUMMER 1974. FIVE-HOUR RETENTION.

Parameter	Pre-harvest[a] Influent	Pre-harvest[a] Control	Pre-harvest[a] Bulrush	First post-harvest[b] Influent	First post-harvest[b] Control	First post-harvest[b] Bulrush	Second post-harvest[c] Influent	Second post-harvest[c] Control	Second post-harvest[c] Bulrush
BOD	38	5	5	65	9	5	40	4	3
COD	42	31	36						
Ammonia N	1.5	2.0	1.2	0.4	0.2	0.1	0.05	0.4	0.004
Total organic N	0.7	0.9	0.7						
Nitrate N				6.6	3.7	9.7	9.5	4.5	3.9
Turbidity (JTU)	8.6	1.8	2.0	23.2	3.1	2.2			
Total phosphorus	22.6	18.2	21.5	21.0	18.1	15.9	22.2	18.2	17.9
Coliform (log col. 100 ml^{-1})	5.69	4.47	4.69	6.41	4.70	4.77	6.32	3.76	4.08
Total solids				988	873	761	860	829	909
Dissolved solids	916	930	910	758	744	687	762	740	749
Suspended solids				232	168	75	93	89	165
pH	7.44	7.85	7.45	7.42	7.67	7.37	7.50	7.66	7.52
Conductivity (umho)	1436	1415	1440	1075	1005	950	1092	1076	1092

[a] All values not specified by parentheses are expressed as mg l^{-1}.

[b] In most cases n = 24 samples taken at 4 hour intervals over a 4-day period.

[c] In most cases n = 19 samples taken at 4 hour intervals over a 3-day period.

Table C-2. WATER BALANCE DATA FOR EXPERIMENTAL BASINS DURING TREATMENT OF SECONDARY EFFLUENT. INTENSIVE STUDIES. SUMMER 1974. (liters)

	Influent	Rainfall	Total effluent	% Evapotranspiration
Pre-harvest				
Control	7843	0	7865	0
Bulrush	7835	0	7067	9.8
First post harvest				
Control	5352	213	7059	-28.6
Bulrush	6022	213	5840	6.3
Second post-harvest				
Control	6109	0	4705	23.0
Bulrush	6408	0	7517	-17.0

Table C-3. EFFECTIVENESS OF EXPERIMENTAL BASINS FOR TREATMENT OF SECONDARY EFFLUENT. SIXTEEN HOUR RETENTION.

		Influent load			Effluent load			%
Parameter	Basins	mg l^{-1}	liters	kg	mg l^{-1}	liters	kg	reduction
BOD	Control	23	19784	0.5	9	11533	0.1	77
	Bulrush	23	26866	0.6	9	18887	0.2	72
COD	Control	31	19784	0.6	42	11533	0.5	21
	Bulrush	31	26866	0.8	31	18887	0.6	29
Orthophosphate	Control	25	19784	0.5	11	11533	0.1	80
	Bulrush	25	26866	0.7	20	18887	0.4	40
Total phosphorus	Control	26	19784	0.5	12	11533	0.1	81
	Bulrush	26	26866	0.7	22	18887	0.4	44
Total solids	Control	822	19784	16.3	603	11533	7.0	57
	Bulrush	822	26866	22.1	591	18887	11.2	49
Suspended solids	Control	75	19784	1.5	74	11533	0.8	43
	Bulrush	75	26866	2.0	79	18887	1.5	25
Dissolved solids	Control	746	19784	14.8	532	11533	6.1	62
	Bulrush	746	26866	20.0	512	18887	9.7	52

Table C-4. EFFECTIVENESS OF EXPERIMENTAL BASINS FOR TREATMENT OF SECONDARY EFFLUENT. TEN-DAY RETENTION.

		Influent load			Effluent load			%
Parameter	Basins	mg l^{-1}	liters	kg	mg l^{-1}	liters	kg	reduction
BOD	Control	31	21397	0.66	15	13013	0.19	71
	Bulrush	31	34337	1.06	11	20590	0.22	79
COD	Control	90	21397	1.92	52	13013	0.68	65
	Bulrush	90	34337	3.09	65	20590	1.33	57
Orthophosphate	Control	22.6	21397	0.48	22.4	13013	0.29	40
	Bulrush	22.6	34337	0.78	21.9	20590	0.45	42
Total phosphorus	Control	22.7	21397	0.49	23.9	13013	0.31	36
	Bulrush	22.7	34337	0.78	26.2	20590	0.53	32
Total solids	Control	969	21397	20.70	910	13013	11.80	43
	Bulrush	969	34337	33.30	1153	20590	23.70	29
Suspended solids	Control	51	21397	1.09	20	13013	0.26	76
	Bulrush	51	34337	1.75	14	20590	0.28	84
Dissolved solids	Control	918	21397	19.6	890	13013	11.60	42
	Bulrush	918	34337	31.5	1140	20590	23.47	25

Table C-5. WATER BALANCE DATA FOR EXPERIMENTAL BASINS DURING TREATMENT OF SECONDARY EFFLUENT. SUMMER 1974. (liter)

	Control	Softstem	Softstem	River	Softstem
Influent	63948	51045	67449	75166	85911
Rainfall	3592	3592	3592	3592	3592
Effluent	56514	38883	60594	73909	77237
% Evapotranspiration	16.3	28.0	14.2	6.1	13.7

APPENDIX D

PILOT PLANT DATA

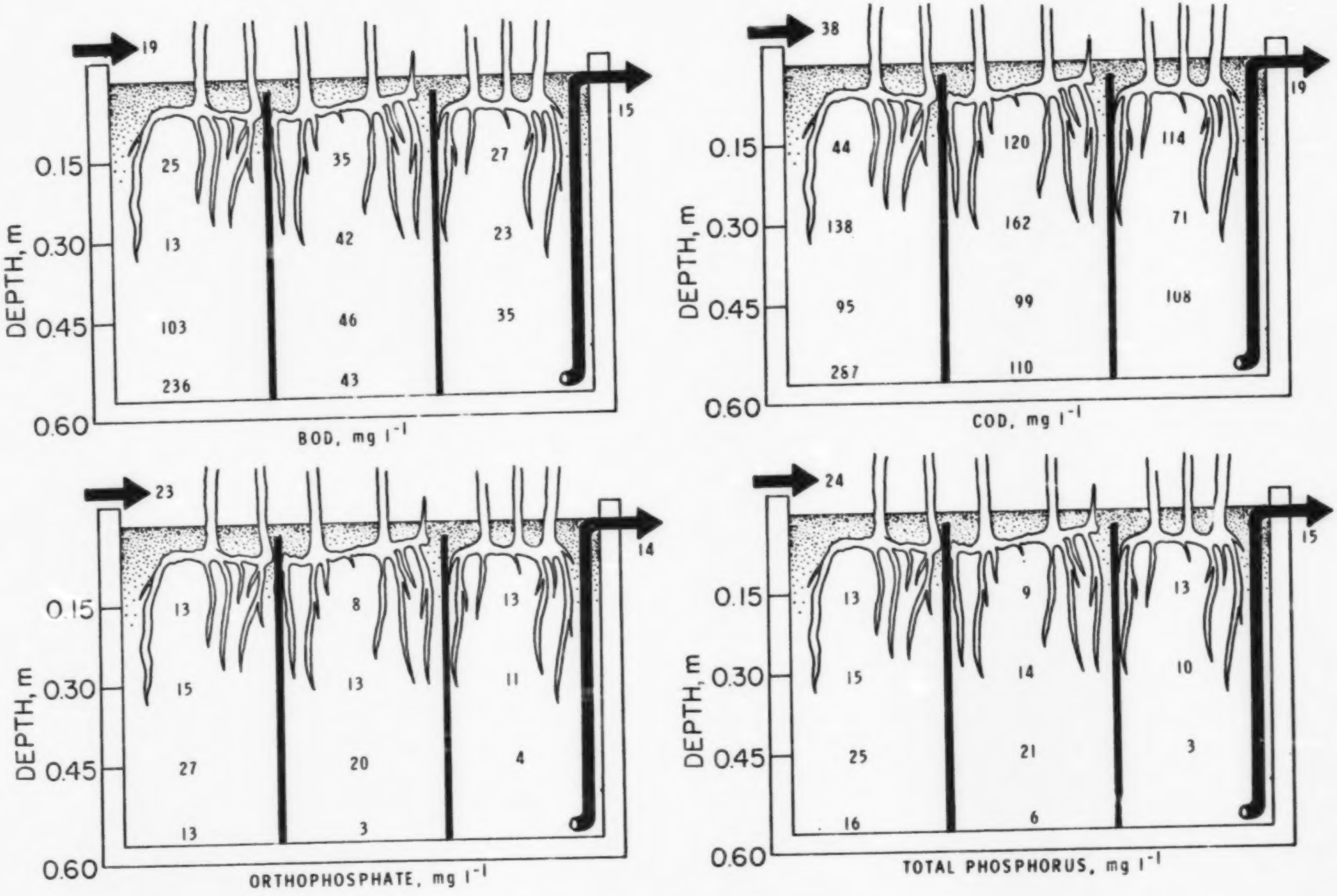


Figure D-1. Water Quality in Pilot Plant Receiving Secondary Effluent. June 5 - July 17, 1975. Each Value is the Mean of Six.

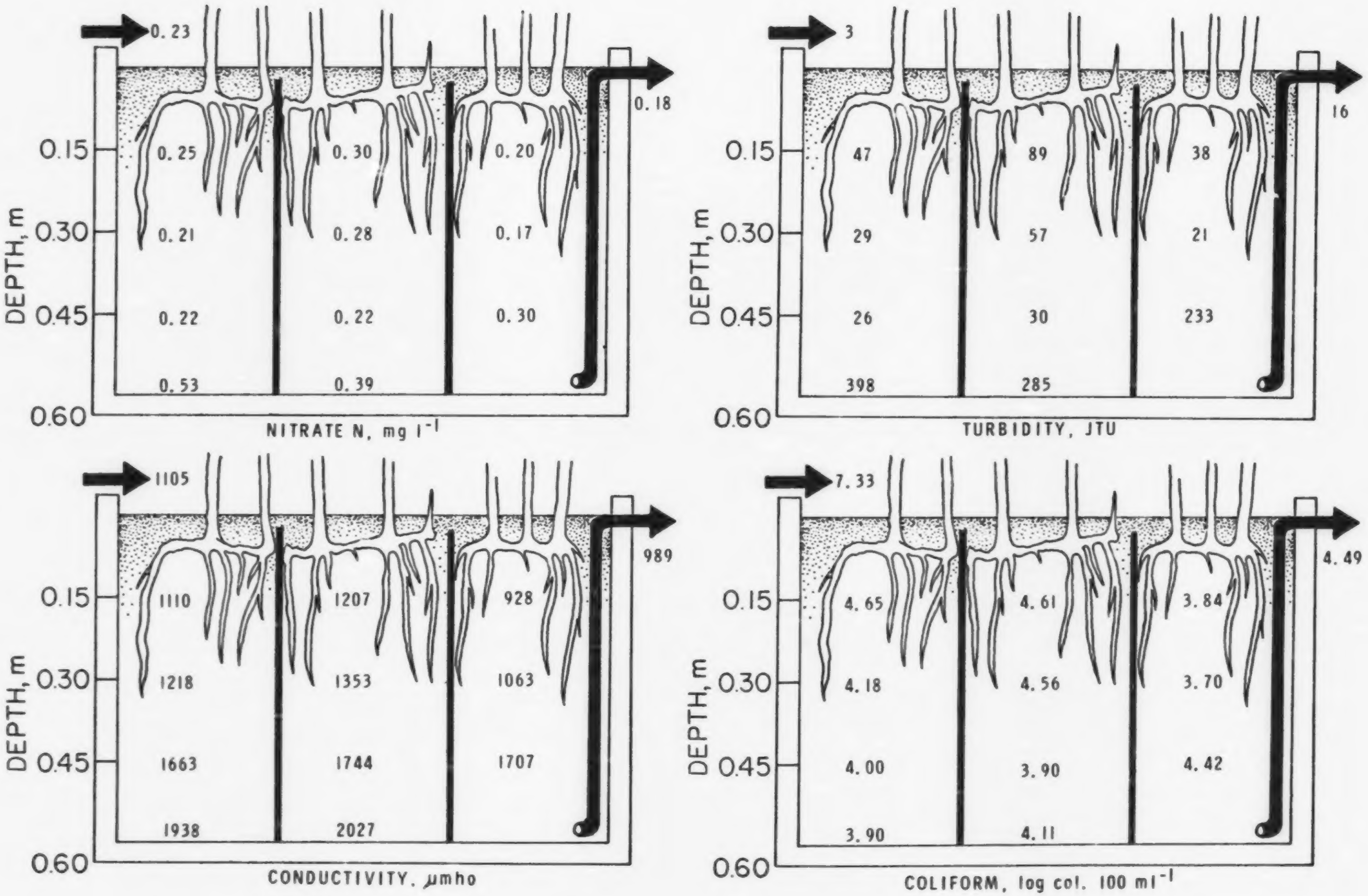


Figure D-1 (continued). June 5 - July 17, 1975.

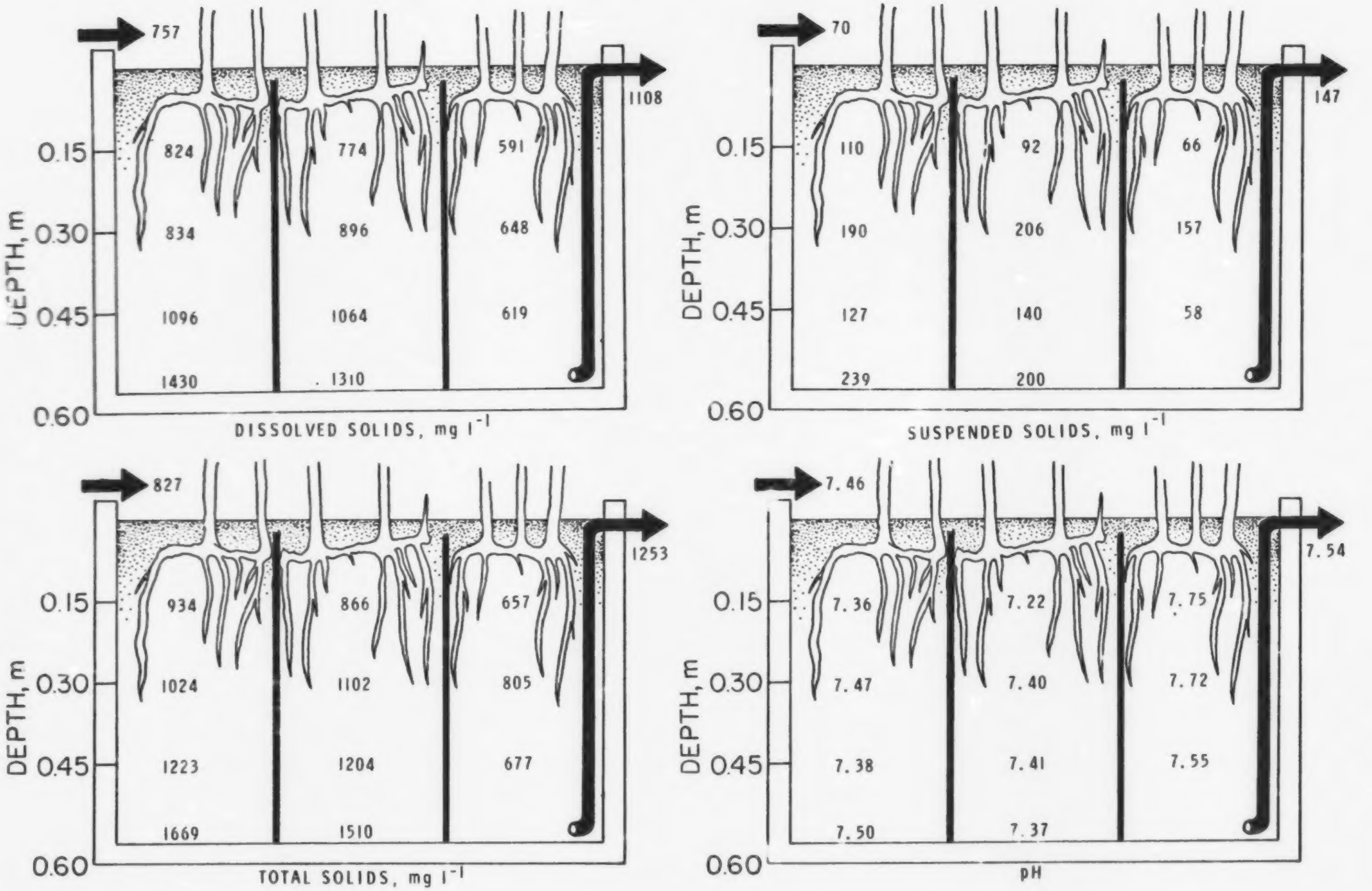


Figure D-1 (continued). June 5 - July 17, 1975.

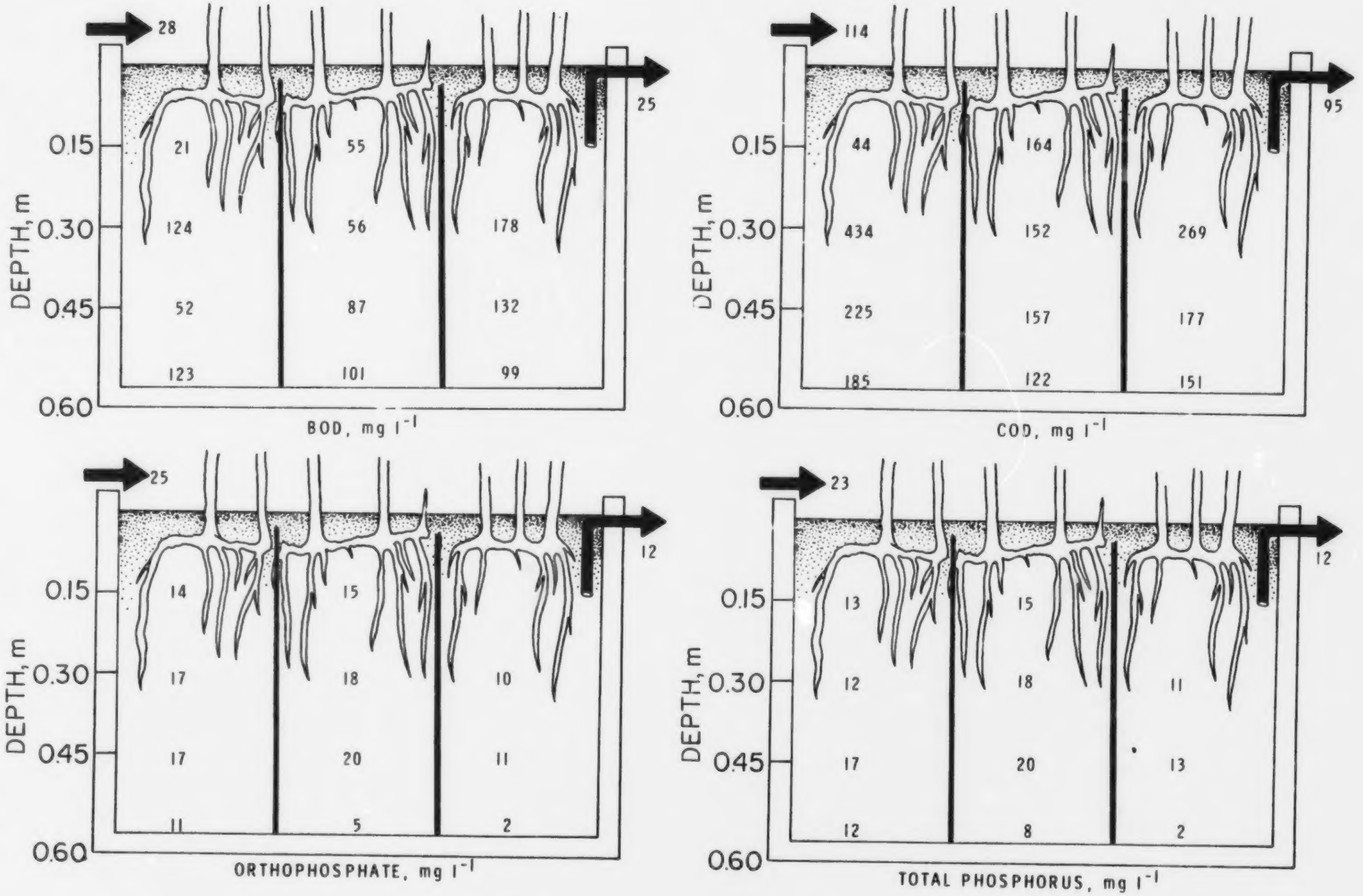


Figure D-2. Water Quality in Pilot Plant Receiving Secondary Effluent. July 17 - August 6, 1975. Each Value is the Mean of Four.

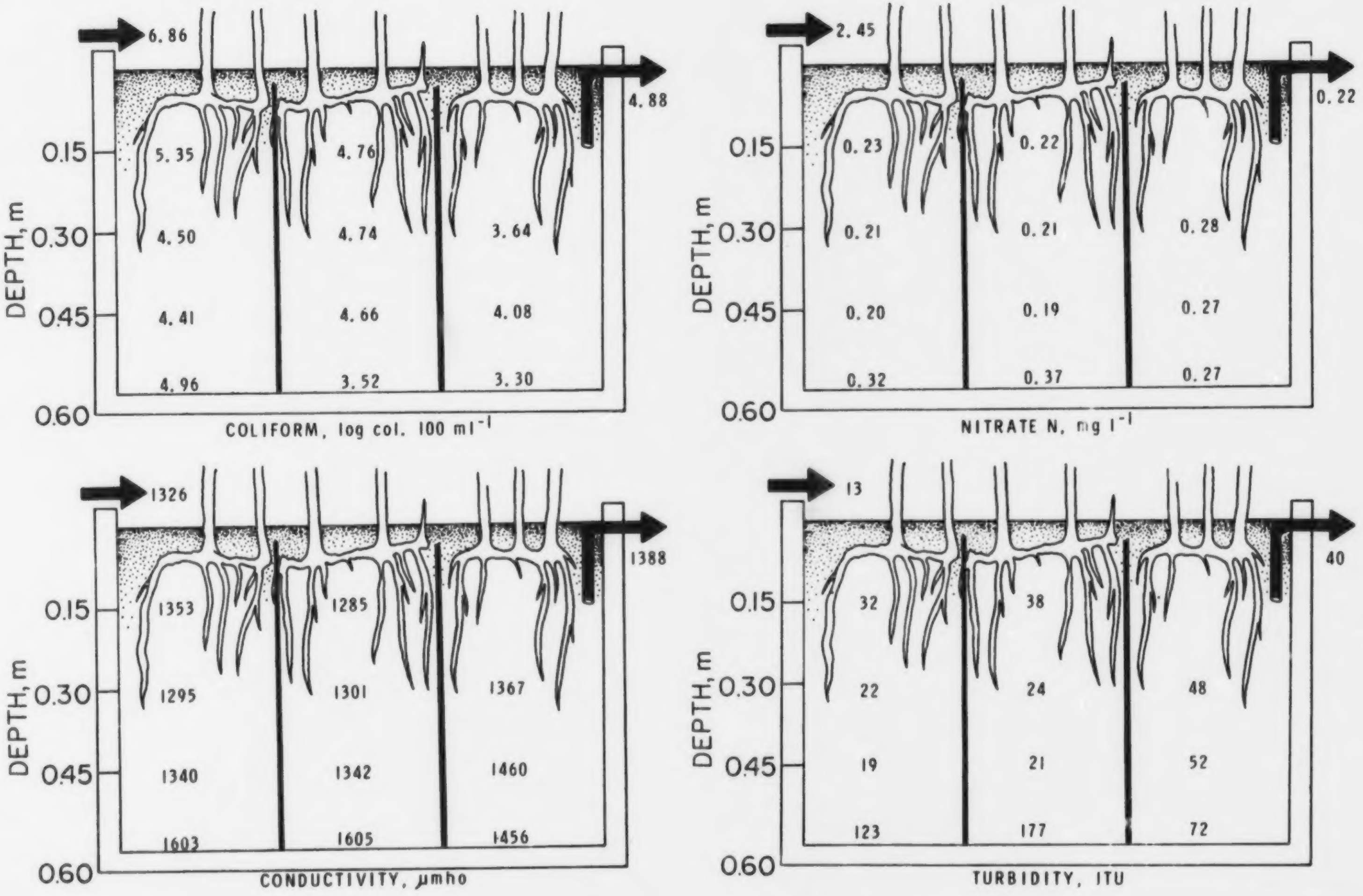


Figure D-2 (continued). July 17 - August 6, 1975.

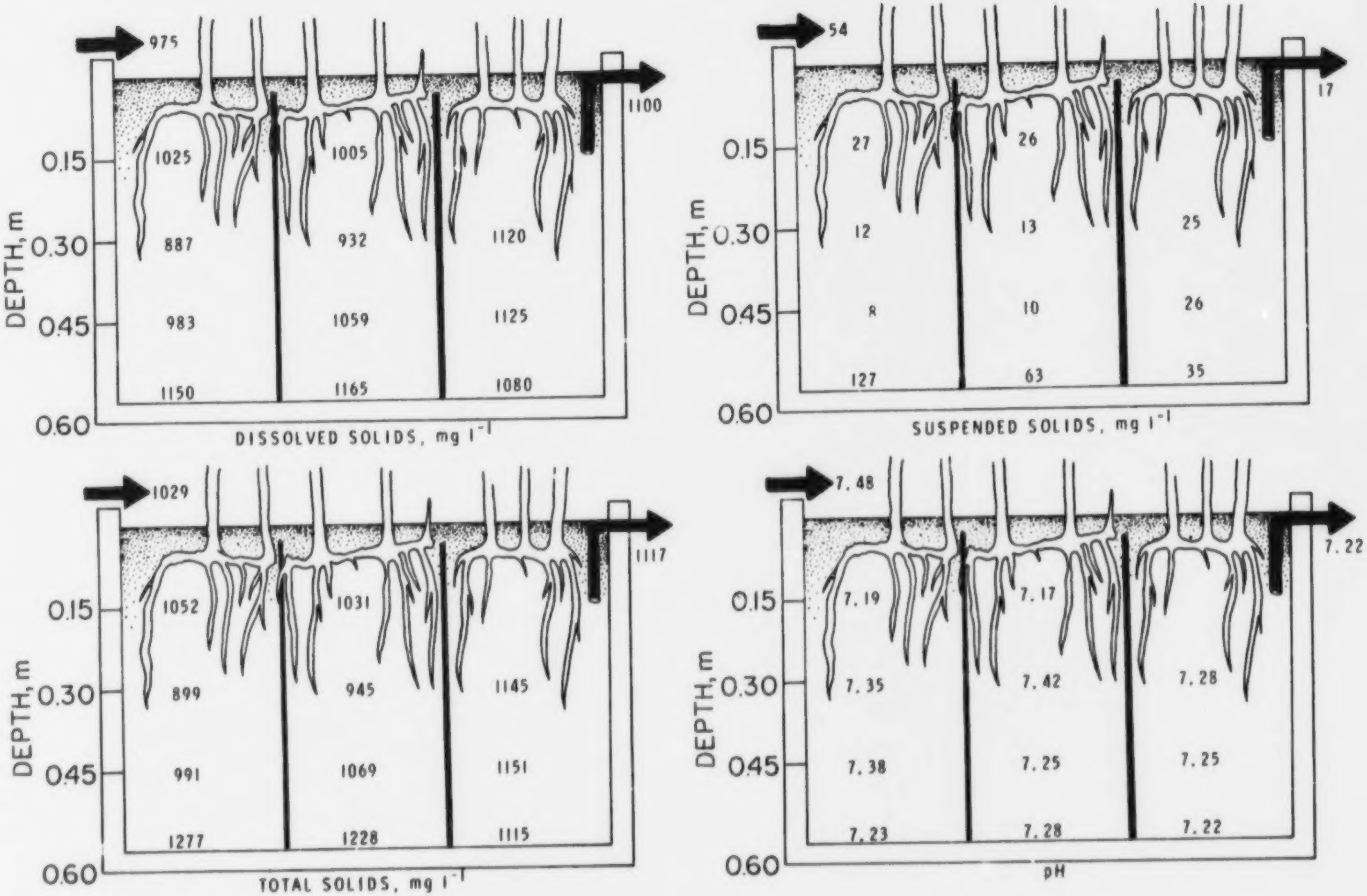


Figure D-2 (continued). July 17 - August 6, 1975.

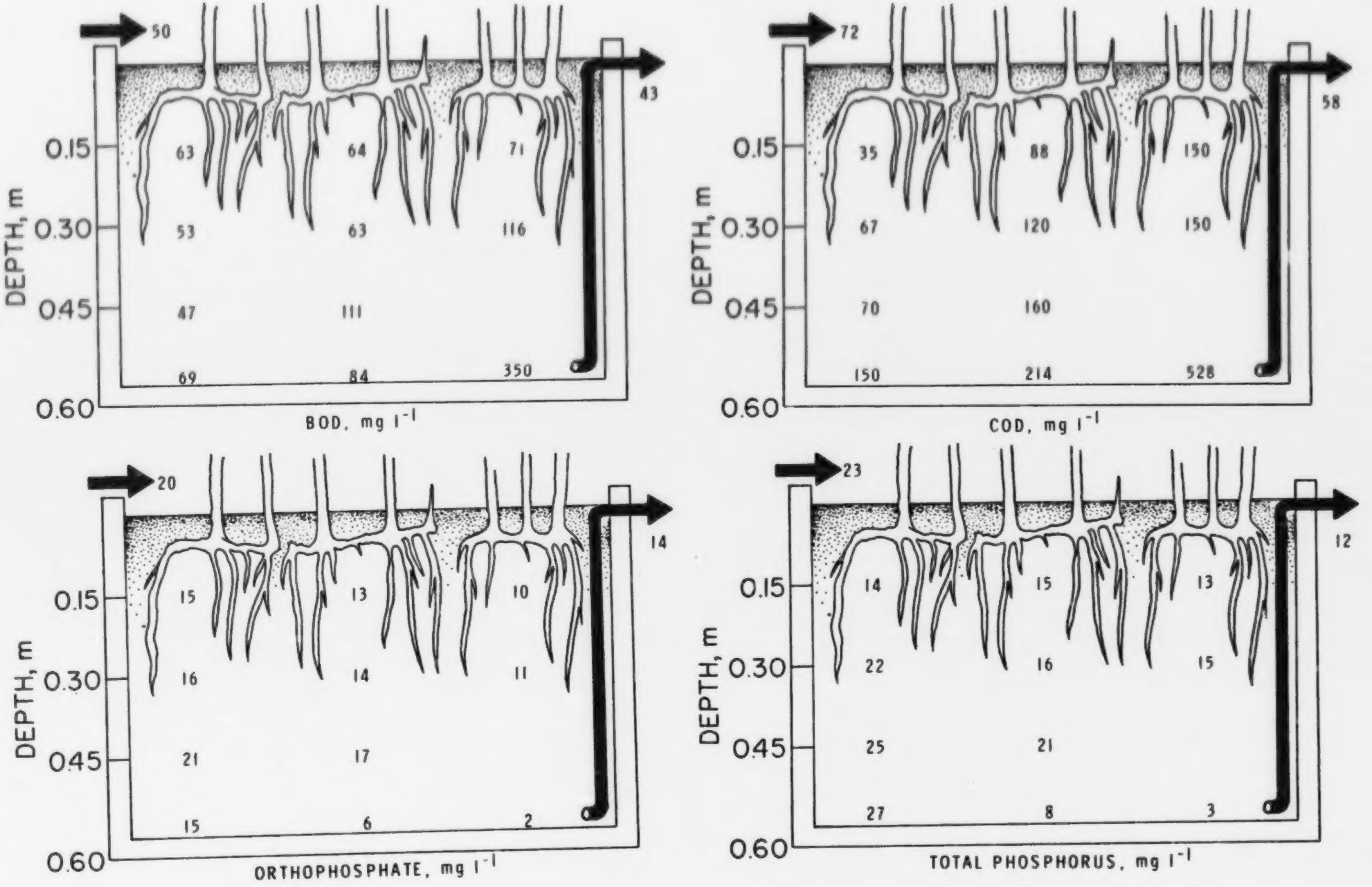


Figure D-3. Water Quality in Pilot Plant Receiving Secondary Effluent. August 6 - August 21, 1975. Each Value is the Mean of Three.

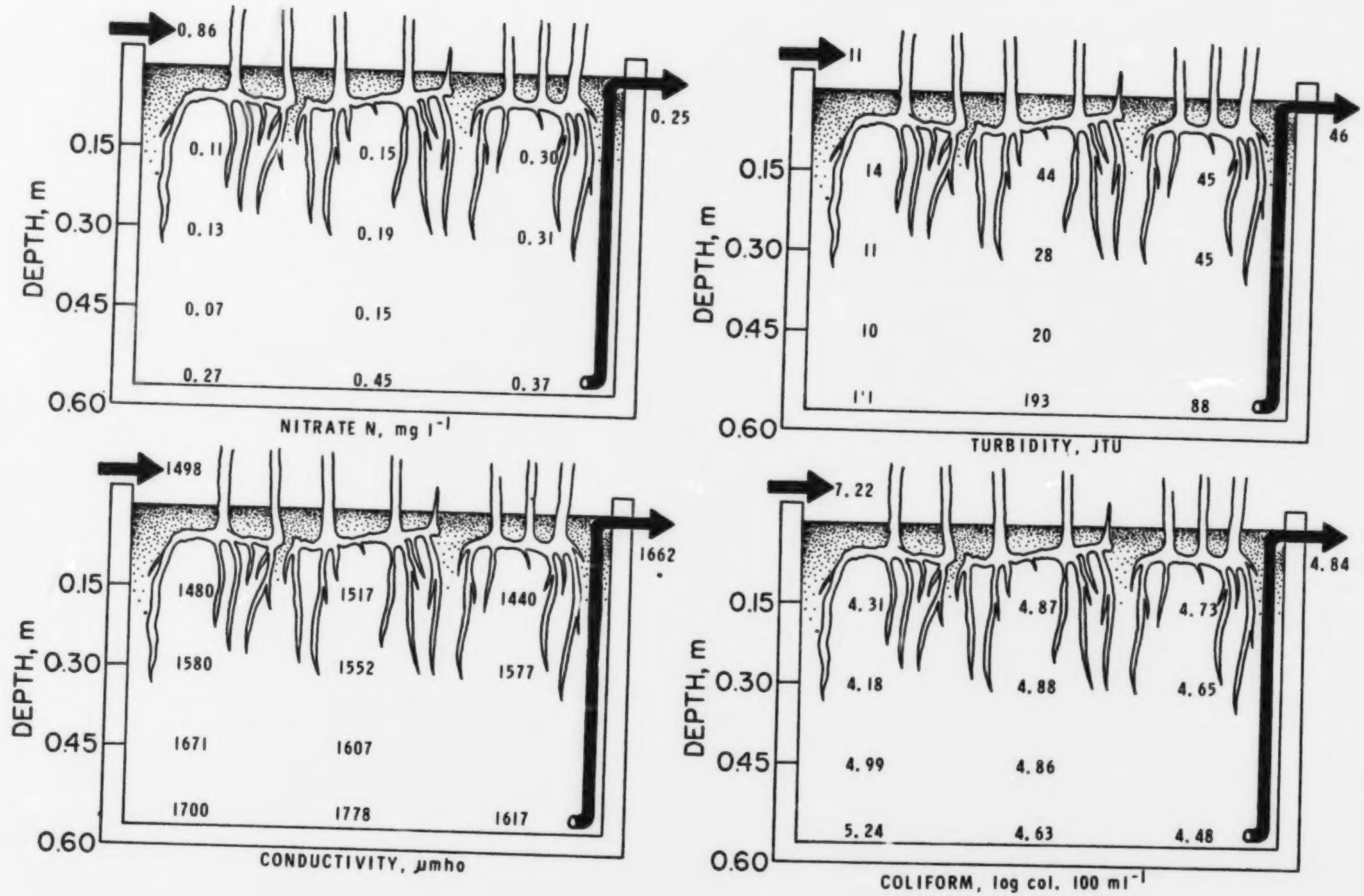


Figure D-3 (continued). August 6 - August 21, 1975.

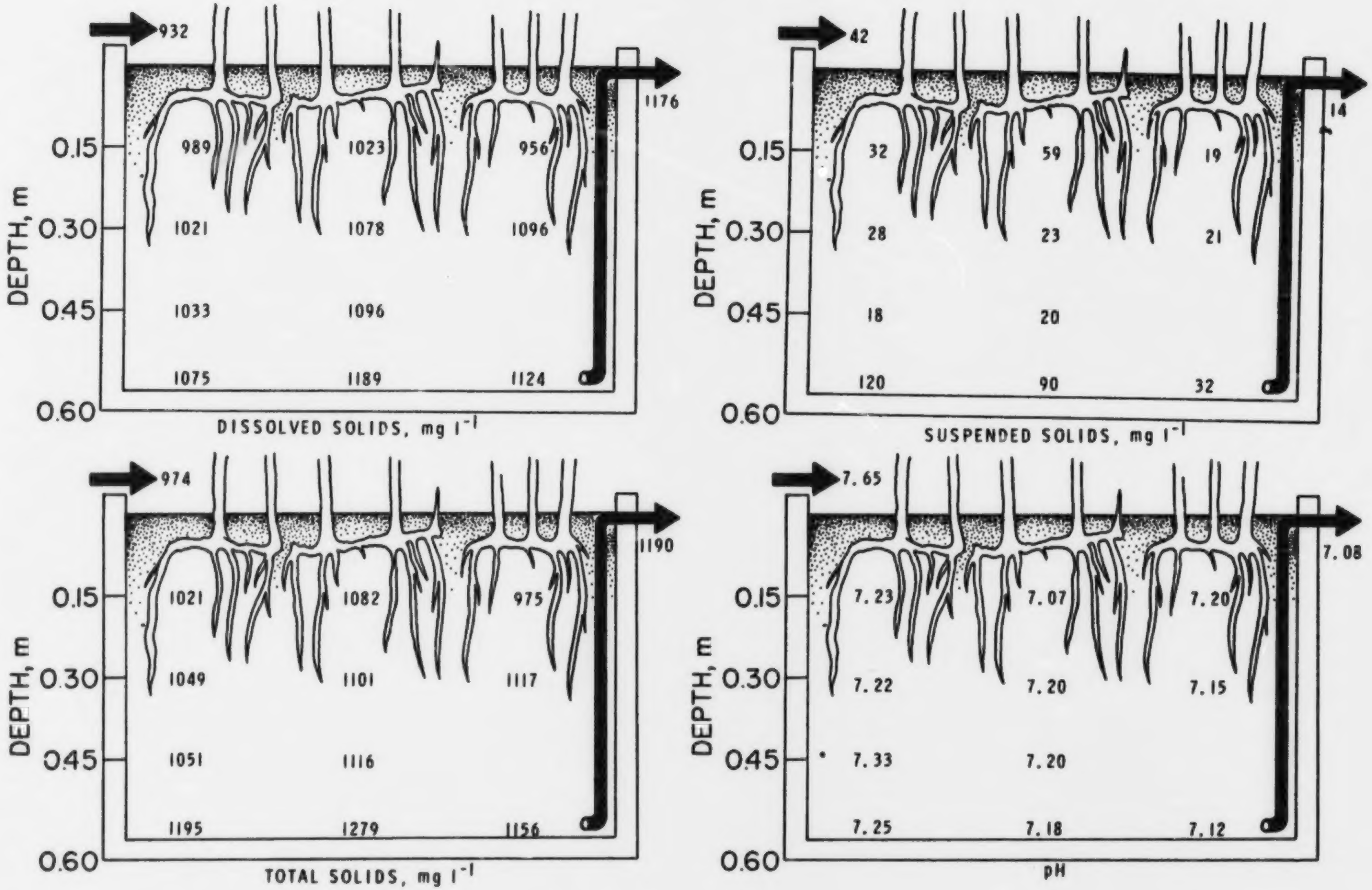


Figure D-3 (continued). August 6 - August 21, 1975.

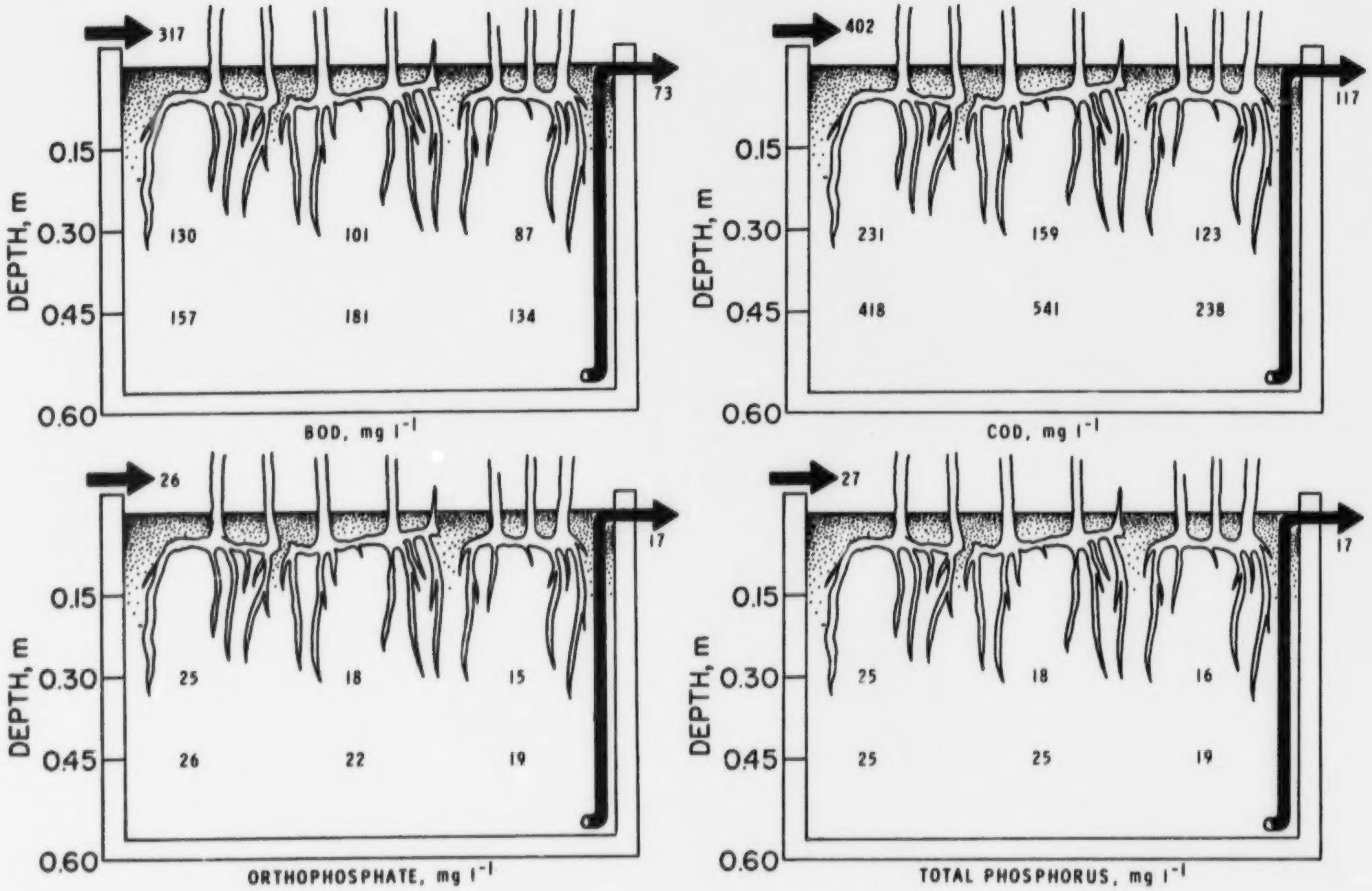


Figure D-4. Water Quality in Pilot Plant Receiving Primary Effluent. August 21 - November 4, 1975. Each Value is the Mean of Twelve.

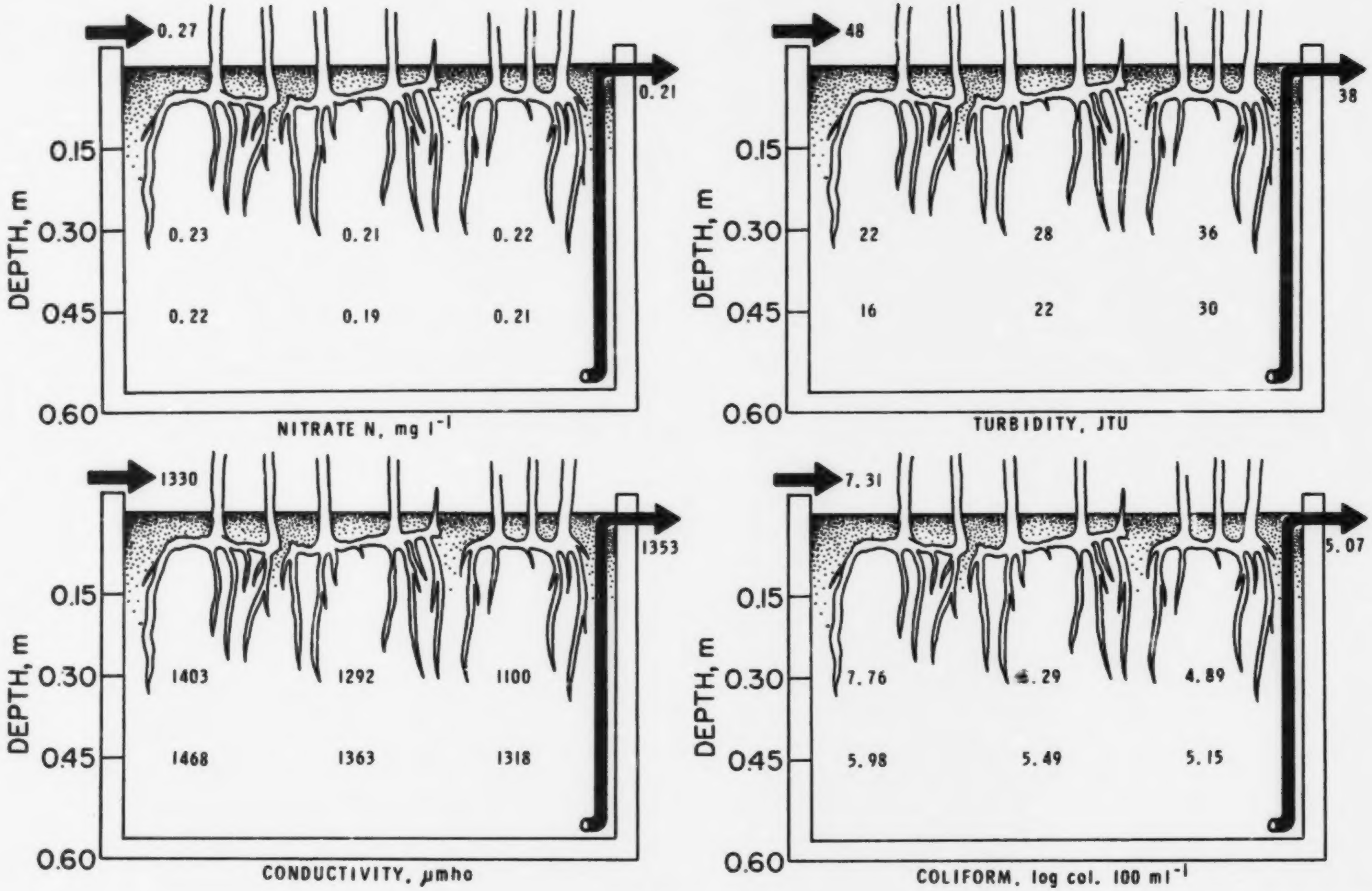


Figure D-4 (continued). August 21 - November 4, 1975.

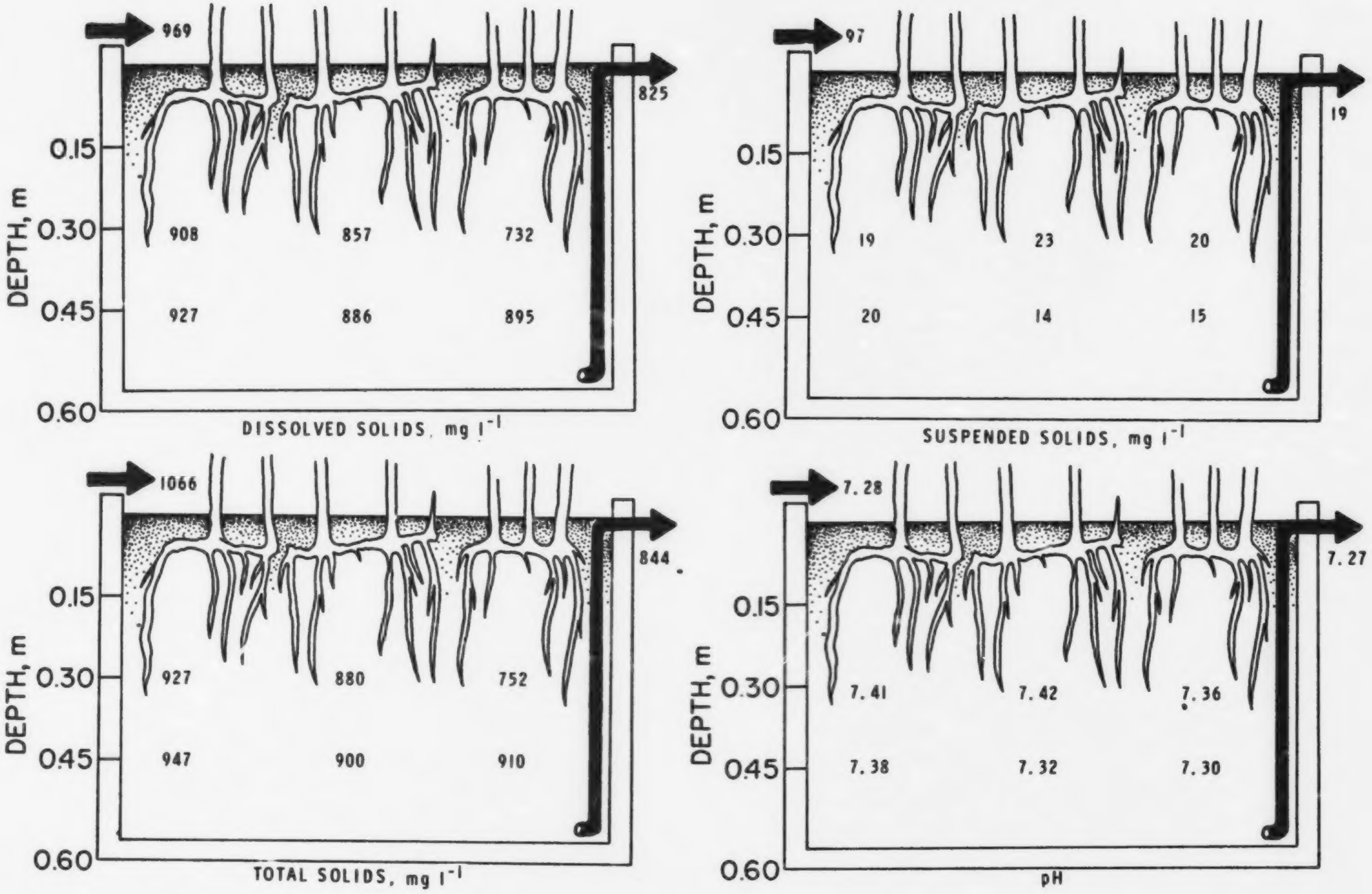


Figure D-4 (continued). August 21 - November 4, 1975.

Table D-1. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT[a]. SUMMER 1974.

Parameter	Source	Mean[b]	Standard deviation	n	% reduction
BOD	Influent	50	24	8	--
	Effluent	4	1	7	92
COD	Influent	42	22	8	--
	Effluent	24	8	8	43
Orthophosphate	Influent	13.4	4.3	10	--
	Effluent	8.5	3.5	9	37
Total phosphorus	Influent	13.9	5.0	10	--
	Effluent	9.0	4.4	9	35
Conductivity (umhos)	Influent	1313	324	7	--
	Effluent	1210	83	7	8
Turbidity (JTU)	Influent	6.2	3.3	10	--
	Effluent	1.3	0.6	9	79
Ammonia	Influent	0.2	0.2		--
	Effluent	0.2	0.5		0
Coliforms (log col. 100 ml^{-1})	Influent	5.58	5.49	6	--
	Effluent	5.63	5.94	5	-9
pH	Influent	7.6	0.09	8	--
	Effluent	7.9	0.09	7	-4

[a] Mean values were not corrected for evapotranspiration.
[b] All values expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table D-2. EFFECTIVENESS OF PILOT PLANT IN TREATING PRIMARY EFFLUENT[a]. SUMMER 1975.

Parameter	Source	Mean[b]	Standard deviation	n	% reduction
BOD	Influent	317	133	10	--
	Effluent	72	36	9	77
COD	Influent	401	158	12	--
	Effluent	117	94	9	71
Orthophosphate	Influent	26	6	12	--
	Effluent	17	3	9	35
Total phosphorus	Influent	27	6	12	--
	Effluent	17	4	9	37
Conductivity (umhos)	Influent	1330	174	12	--
	Effluent	1353	160	9	-2
Turbidity (JTU)	Influent	48	16	12	--
	Effluent	38	5	9	21
Nitrate N	Influent	0.27	0.27	10	--
	Effluent	0.21	0.09	9	22
Coliform (log col. 100 ml^{-1})	Influent	7.31	6.72	7	--
	Effluent	5.07	5.17	6	99.9
pH	Influent	7.28	0.12	12	--
	Effluent	7.27	0.23	9	--
Total solids	Influent	973	113	3	--
	Effluent	1156	19	2	-19
Dissolved solids	Influent	42	47	3	--
	Effluent	32	14	2	23
Suspended solids	Influent	932	84	3	--
	Effluent	1124	34	2	-21

[a] Mean values were not corrected for evapotranspiration.

[b] All values expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table D-3. AVERAGE VALUES FOR SEVERAL PARAMETERS AT THREE DEPTHS IN PILOT PLANT DURING AN INTENSIVE STUDY. JULY 7 - JULY 10, 1975.

Parameter	Mean[a]	Standard deviation	Low	High
Influent				
BOD	12.22	5.06	7.71	27.34
COD	47.14	41.25	23.52	186.20
Turbidity (JTU)	7.35	7.34	2.00	23.00
pH	7.44	0.19	7.15	7.70
Conductivity (umho)	1200	125	900	1330
Nitrate N	2.84	1.88	0.00	6.40
Total phosphorus	24.52	4.28	17.03	32.78
Total solids	932.18	77.14	774.50	1096.00
Suspended solids	18.63	13.06	0.00	38.50
Dissolved solids	913.55	80.03	746.50	1078.00
Coliform (log col. 100 ml^{-1})	5.96	6.06	3.32	6.60
Downstream end; 0.15 m				
BOD	64.67	19.20	41.34	85.33
Turbidity (JTU)	25.29	10.90	11.00	46.00
pH	7.57	0.26	7.20	7.90
Conductivity (umho)	1056	119	800	1210
Nitrate N	0.26	0.07	0.17	0.37
Total phosphorus	9.46	1.50	6.92	12.75
Total solids	874.13	113.04	510.00	1103.50
Suspended solids	28.05	19.75	0.00	82.00
Dissolved solids	846.08	137.35	469.50	1078.50
Coliform (log col. 100 ml^{-1})	3.85	3.88	2.47	4.34
Downstream end; 0.45 m				
BOD	14.25	6.92	8.67	33.33
COD	49.65	29.98	23.52	68.60
Turbidity (JTU)	46.89	15.80	26.00	76.00
pH	7.37	0.16	7.10	7.70
Conductivity (umho)	1278	122	1100	1500
Nitrate N	0.29	0.07	0.20	0.42
Total phosphorus	8.43	1.51	5.31	10.12
Total solids	996.69	119.95	662.20	1181.00
Suspended solids	29.68	12.67	11.00	50.50
Dissolved solids	967.01	120.16	645.20	1133.50
Coliform (log col. 100 ml^{-1})	3.98	4.09	3.00	3.97

[a] All values are mg l^{-1} unless otherwise indicated.

Table D-3 (continued). AVERAGE VALUES DURING INTENSIVE STUDY.
JULY 7 - JULY 10, 1975

Parameter	Mean[a]	Standard deviation	Low	High
Downstream end; 0.60 m				
BOD	26.27	14.18	8.67	43.00
COD	Not tested			
Turbidity (JTU)	51.11	20.70	30.00	96.00
pH	7.32	0.19	7.10	7.55
Conductivity (umho)	1448	108	1250	1610
Nitrate N	0.32	0.07	0.21	0.48
Total phosphorus	24.52	4.28	17.03	32.78
Total solids	1181.89	107.97	1027.50	1442.50
Suspended solids	49.76	14.68	16.50	69.50
Dissolved solids	1132.13	111.71	973.50	1388.50
Coliforms (log col. 100 ml^{-1}	3.30	3.23	2.78	3.48

[a] All values are mg l^{-1} unless otherwise indicated.

Table D-4. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT (DRAIN AT 0.6 m).[a] SUMMER 1975.

Parameter	Source	Mean[b]	Standard deviation	n	% reduction
BOD	Influent	19	15	6	--
	Effluent	15	5	6	21
COD	Influent	38	21	6	--
	Effluent	41	18	6	42
Orthophosphate	Influent	23	8	7	--
	Effluent	14	5	7	39
Total phosphorus	Influent	24	7	7	--
	Effluent	15	5	7	38
Conductivity (umhos)	Influent	1125	158	7	--
	Effluent	989	283	7	10
Turbidity (JTU)	Influent	4.6	5	7	--
	Effluent	15.5	11	7	-474
Nitrate N	Influent	0.32	0.26	7	--
	Effluent	0.18	0.06	6	22
Coliforms (log col. 100 ml-1)	Influent	6.2	3.4	7	--
	Effluent	3.90	3.2	7	99.9
pH	Influent	7.42	0.18	7	--
	Effluent	7.54	0.15	7	--
Total solids	Influent	827	48	7	--
	Effluent	1253	162	7	-52
Dissolved solids	Influent	757	72	7	--
	Effluent	1107	201	7	-46
Suspended solids	Influent	70	43	7	--
	Effluent	147	151	7	-110

[a] Mean values were not corrected for evapotranspiration.

[b] All values expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table D-5. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT (DRAIN AT 0.15 m)[a]. SUMMER 1975.

Parameter	Source	Mean[b]	Standard deviation	n	% reduction
BOD	Influent	28	19	4	--
	Effluent	25	16	4	11
COD	Influent	115	98	5	--
	Effluent	95	89	3	17
Orthophosphate	Influent	25	10	5	--
	Effluent	12	1	3	52
Total phosphorus	Influent	24	8	5	--
	Effluent	12	1	3	50
Conductivity (umhos)	Influent	1326	240	5	--
	Effluent	1388	183	3	-5
Turbidity (JTU)	Influent	13	19	5	--
	Effluent	40	14	3	-208
Nitrate N	Influent	2.45	4.70	5	--
	Effluent	0.22	0.04	3	91
Total Coliforms (log col. 100 ml^{-1})	Influent	6.86	6.66	4	--
	Effluent	4.88	6.00	3	99.9
pH	Influent	7.48	0.23	5	--
	Effluent	7.22	0.16	3	--
Total solids	Influent	1029	180	4	--
	Effluent	1117	90	4	-9
Suspended solids	Influent	54	87	4	--
	Effluent	18	10	4	68
Dissolved solids	Influent	974	112	4	--
	Effluent	1099	83	4	-13

[a] Mean values were not corrected for evapotranspiration.

[b] All values expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table D-6. EFFECTIVENESS OF PILOT PLANT IN TREATING SECONDARY EFFLUENT (PARTITIONS REMOVED)[a]. SUMMER.

Parameter	Source	Mean[b]	Standard deviation	n	% reduction
BOD	Influent	50	11	3	--
	Effluent	43	34	3	14
COD	Influent	72	33	3	--
	Effluent	58	9.3	3	19
Orthophosphate	Influent	20	0.58	3	--
	Effluent	14	2.9	3	30
Total phosphorus	Influent	23	5.9	3	--
	Effluent	12	0.91	3	48
Conductivity (umhos)	Influent	1498	194	3	--
	Effluent	1662	46	3	-11
Turbidity (JTU)	Influent	11	11	3	--
	Effluent	46	8.1	3	-318
Nitrate N	Influent	0.86	0.08	2	--
	Effluent	0.25	0.15	3	71
Coliforms (log col. 100 ml^{-1})	Influent	7.2	7.5	3	--
	Effluent	4.8	4.4	3	99.9
pH	Influent	7.7	0.17	3	--
	Effluent	7.1	0.10	3	--
Total solids	Influent	1066	147	12	--
	Effluent	845	309	10	21
Dissolved solids	Influent	970	121	12	--
	Effluent	825	303	10	15
Suspended solids	Influent	97	62	12	--
	Effluent	19	18	10	4.1

[a] Mean values were not corrected for evapotranspiration.

[b] All values expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table D-7. WATER BALANCE DATA FOR PILOT PLANT.
(liters)

Sampling dates	Influent	Rainfall	Total effluent	% evapotranspiration
June 5 - Aug. 31 1974	607227	22301	604468	4.0
June 5 - July 17 1975	119200	22153	108255	23.4
July 17 - Aug. 6 1975	57036	1628	39376	32.8
Aug. 6 - Aug. 21 1975	44924	6154	35919	29.7
Aug. 21 - Nov. 4 1975	188273	37019	187376	16.8

APPENDIX E

DATA RELATED TO PHOSPHORUS DISTRIBUTION

Table E-1. DISTRIBUTION OF DRY MATTER IN GRAVEL PILOT PLANT (g dw m^{-2})

Depth	Basin A	Basin B	Basin C	Mean
0-15 cm[a]	533	1385	944	970
15-30 cm[b]	1761	1427	1722	1636
30-45 cm[c]	1037	2806	1449	1764
45-60 cm[c]	1037	2806	1449	1764
Total	4368	8424	5614	6135

[a] Each value is the mean of three.
[b] Each value is the result of analysis of a single sample.
[c] Each value represents a single sample taken at 45 cm and assumed to be representative of both depth intervals.

Table E-2. DISTRIBUTION OF ORGANIC MATTER IN GRAVEL PILOT PLANT (g ash-free dw m^{-2})

Depth	Basin A	Basin B	Basin C	Mean
0-15 cm[a]	423	1072	697	731
15-30 cm[b]	1599	1295	1549	1481
30-45 cm[c]	888	2427	1149	1488
45-60 cm[c]	888	2427	1149	1488
Total	3798	7221	4544	5188

[a] Each value is the mean of three.
[b] Each value is the result of analysis of a single sample.
[c] Each value represents a single sample taken at 45 cm and assumed to be representative of both depth intervals.

Table E-3. NUMBER AND SIZE OF BULRUSH SHOOTS IN PILOT PLANT ON AUGUST 8, 1975.

	Length (m)	Diameter (cm)	Number Shoots (m^{-2})
East Basin			
Sample A	0.89	0.77	124
B	1.26	0.68	532
C	1.44	0.74	604
Mean	1.20	0.73	420
Central Basin			
Sample A	1.05	0.78	232
B	0.99	0.60	620
C	0.93	0.89	76
Mean	0.99	0.76	308
West Basin			
Sample A	0.81	0.50	512
B	0.73	0.56	140
C	0.83	0.66	72
Mean	0.79	0.57	240

APPENDIX F

BRILLION MARSH DATA

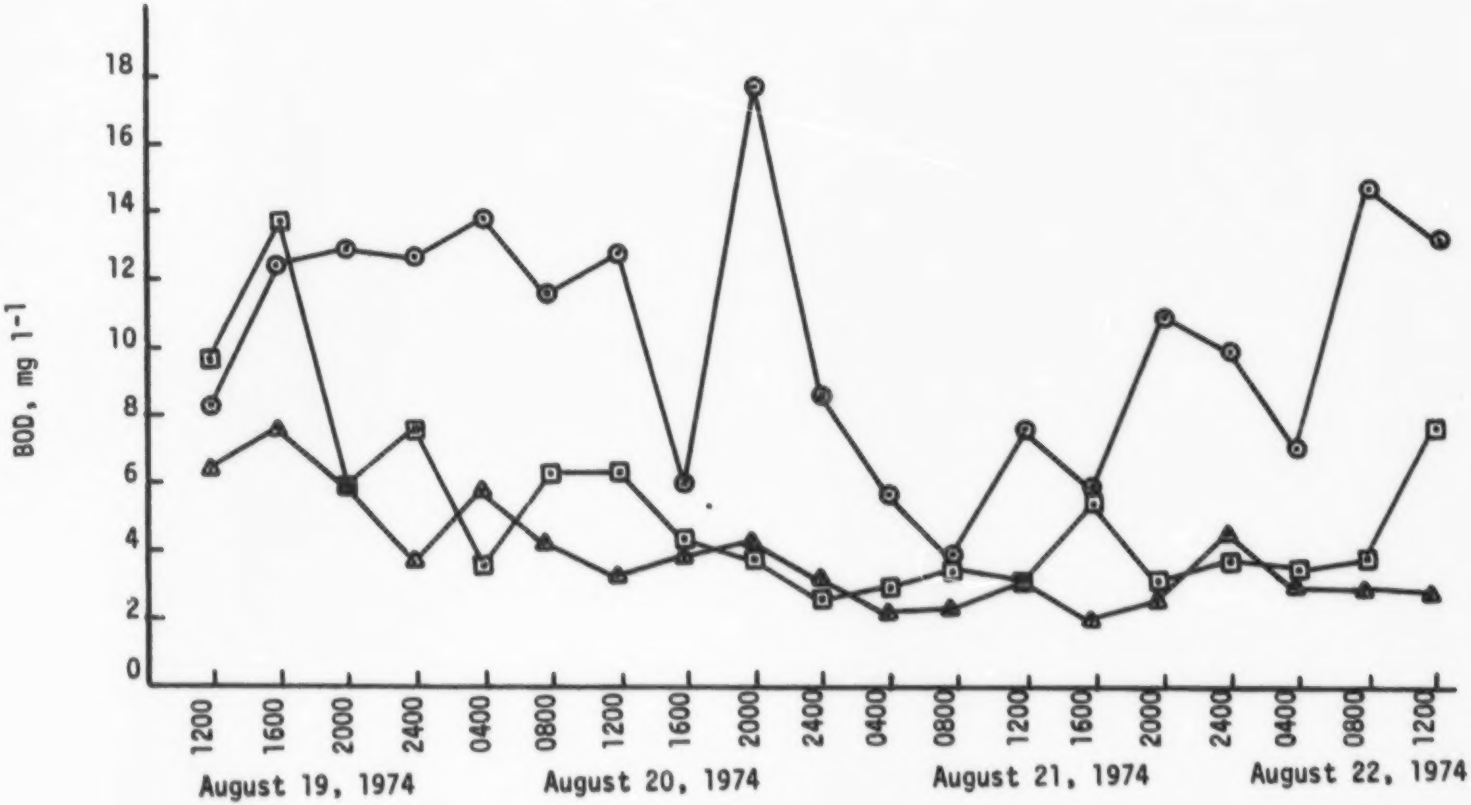


Figure F-1. Short Term Variation in BOD Concentration in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ⊡ - Station III)

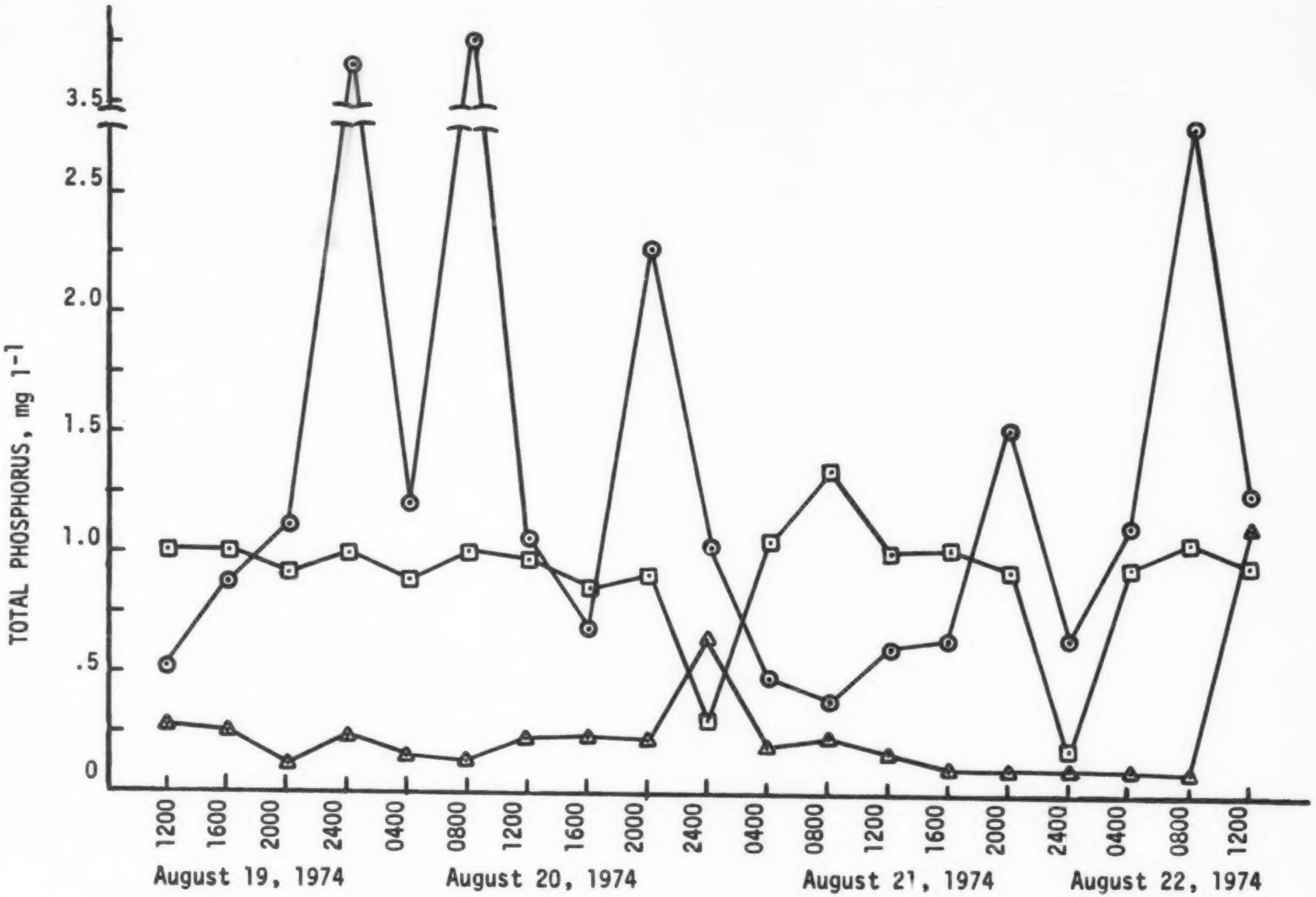


Figure F-2. Short Term Variation in Total Phosphorus Concentration in the Brillion Marsh Study.
(△ - Station I; ⊙ - Station II; ⊡ - Station III)

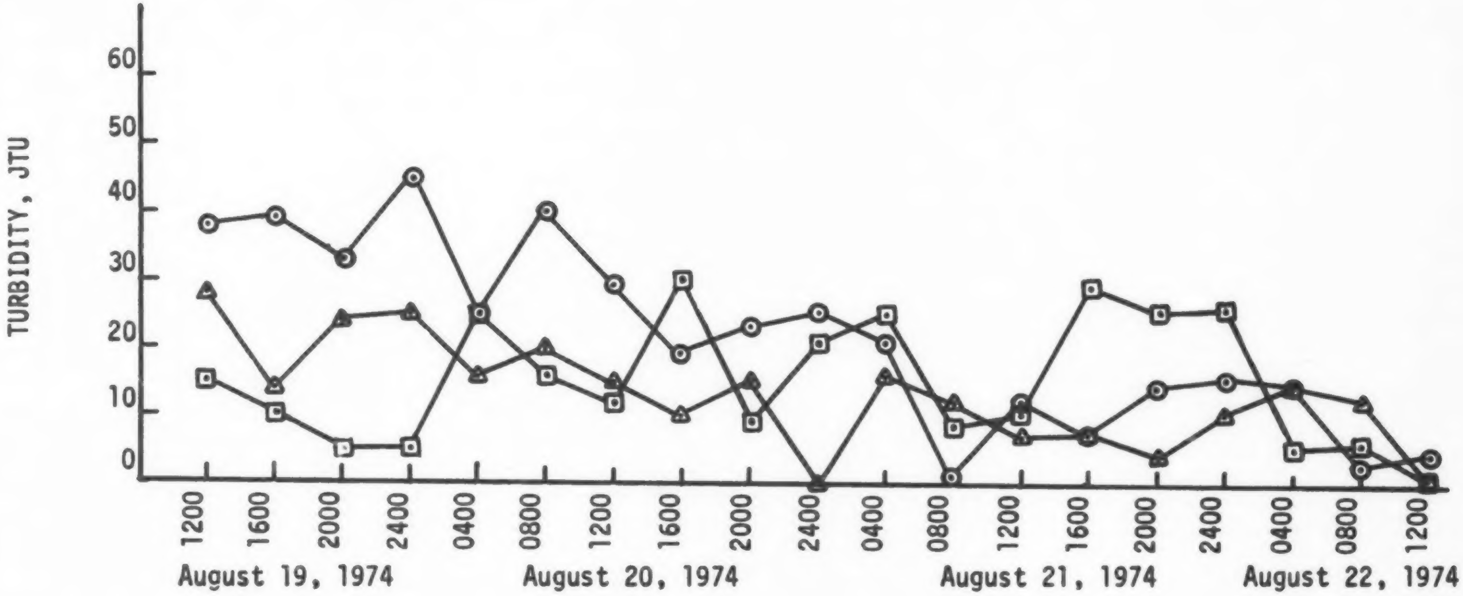


Figure F-3. Short Term Variation in Turbidity in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ⊡ - Station III)

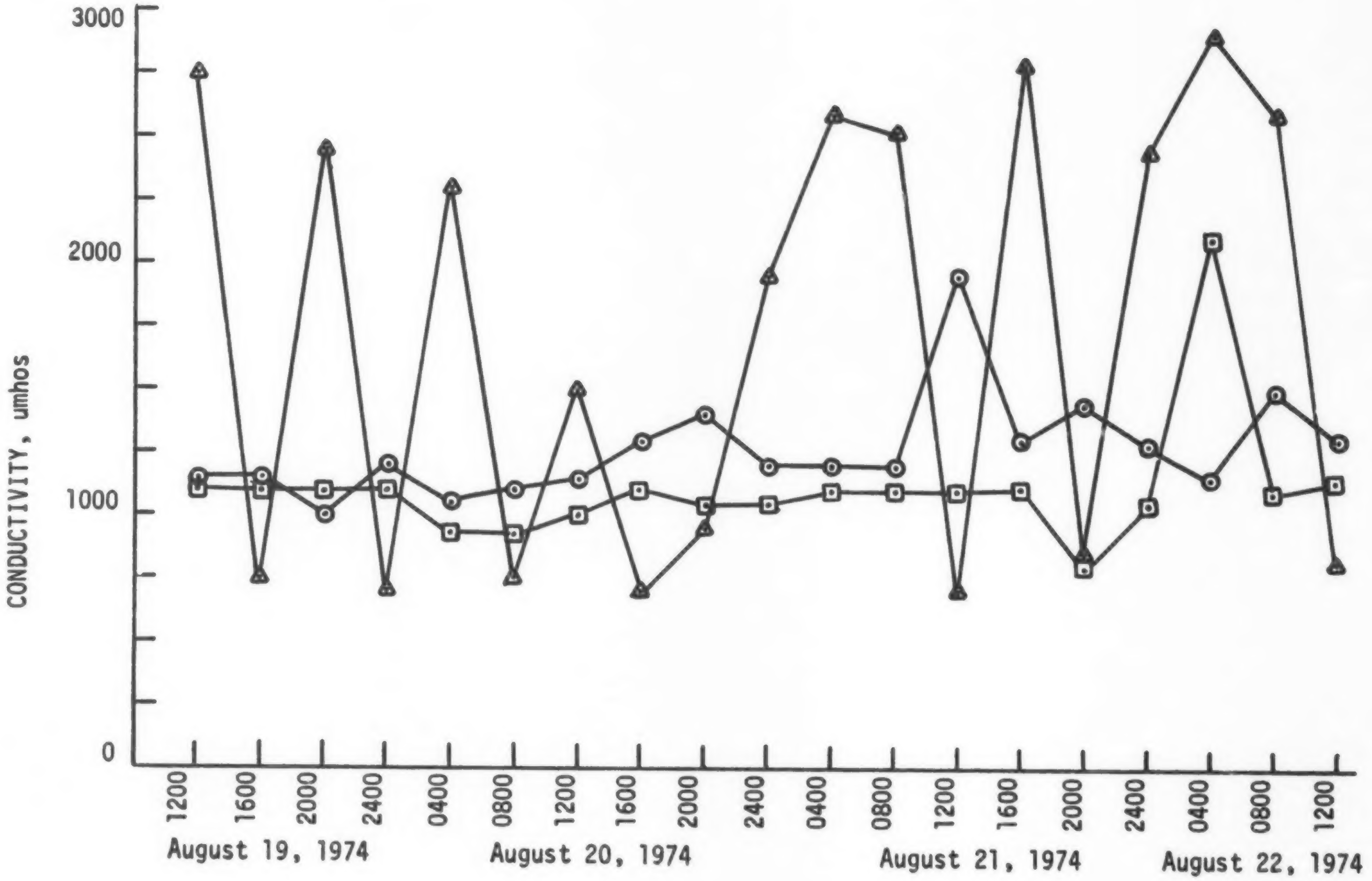


Figure F-4. Short Term Variation in Conductivity in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ▣ - Station III)

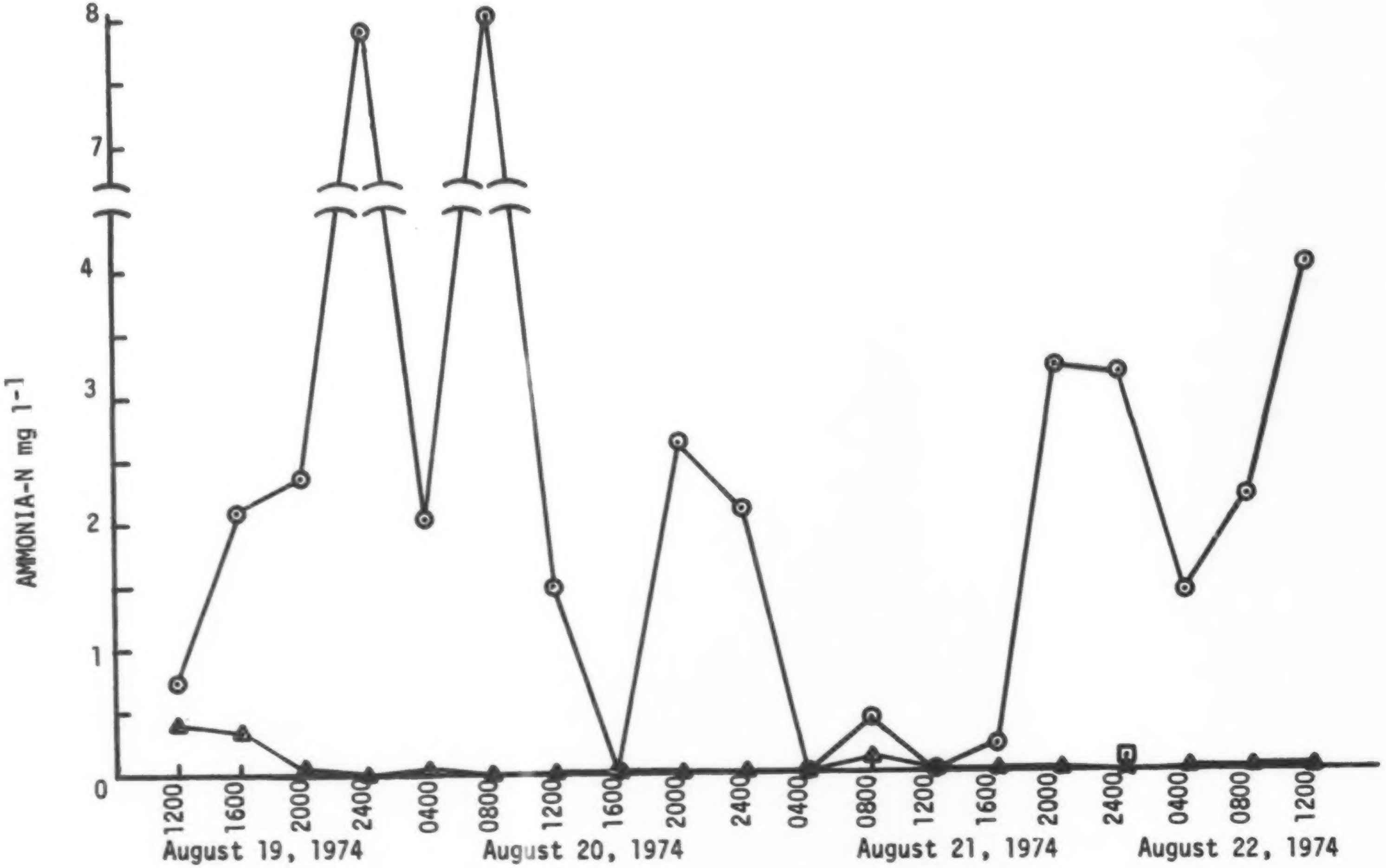


Figure F-5. Short Term Variation in Ammonia Concentration in Total Solids in the Brillion Marsh Study. (△- Station I; ⊙- Station II; ⊡ - Station III)

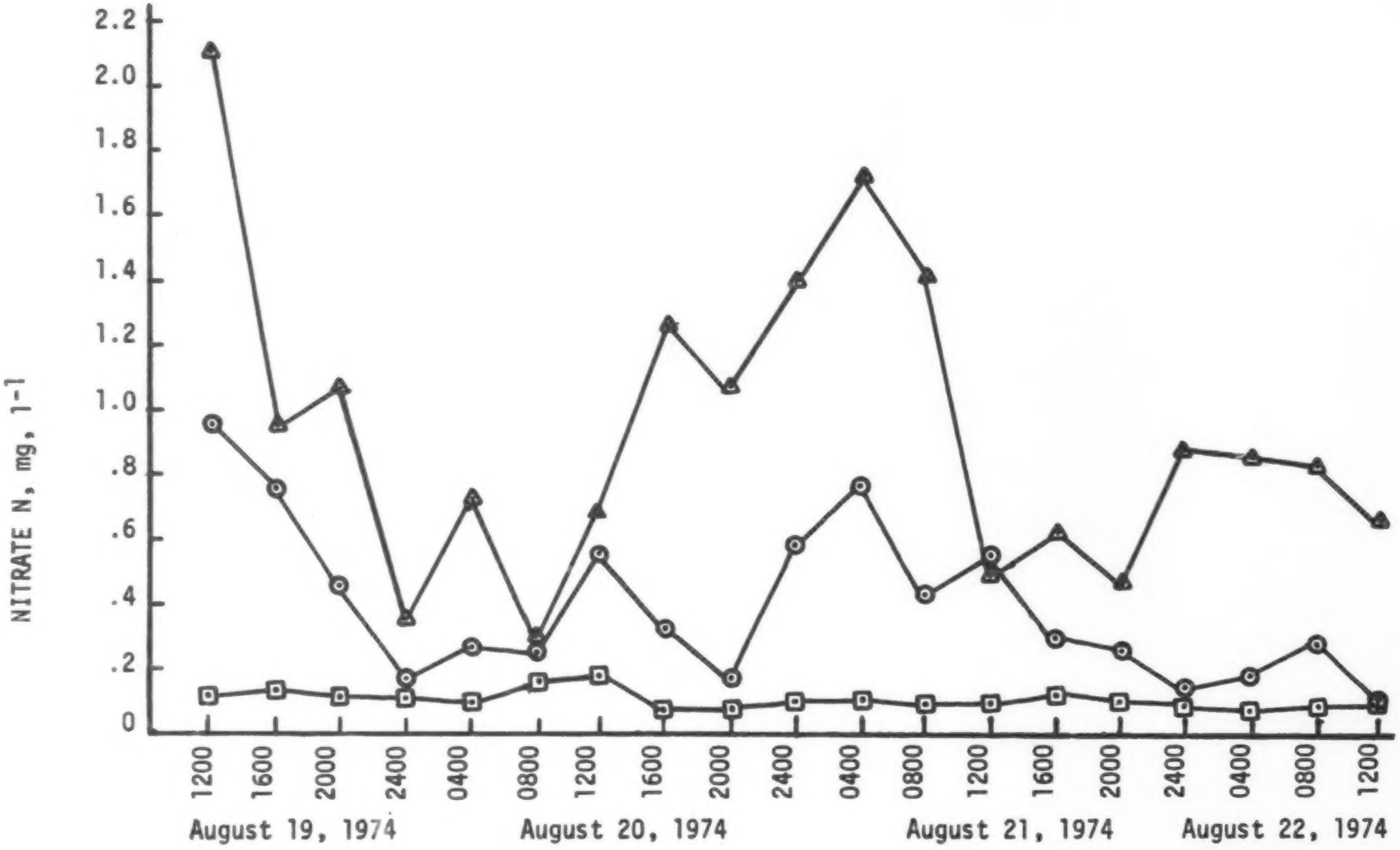


Figure F-6. Short Term Variation in Nitrate Concentration in Total Solids in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ⊡ - Station III)

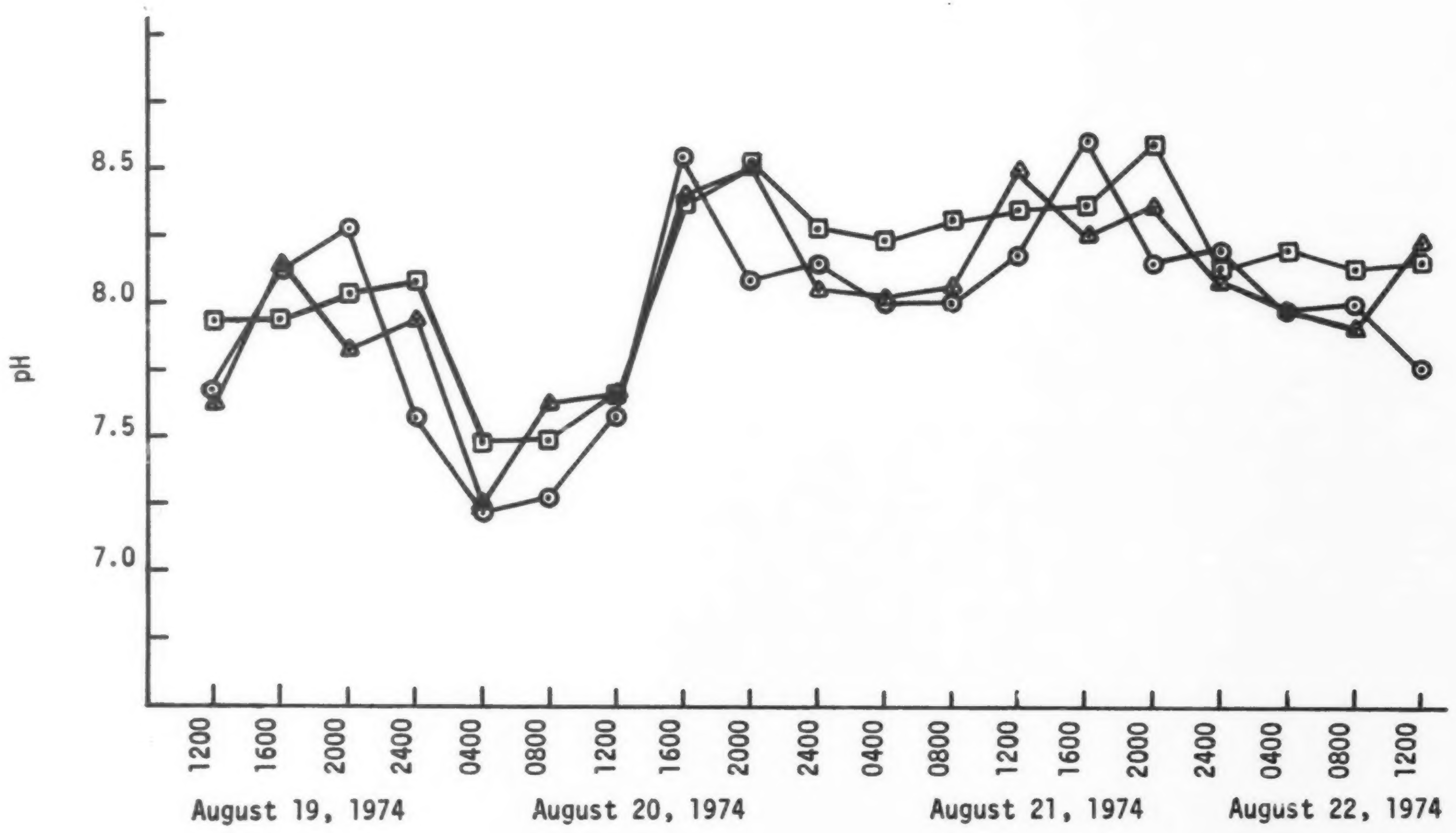


Figure F-7. Short Term Variation in pH in the Brillion Marsh Study.
(△- Station I; ⊙ - Station II; ⊡ - Station III)

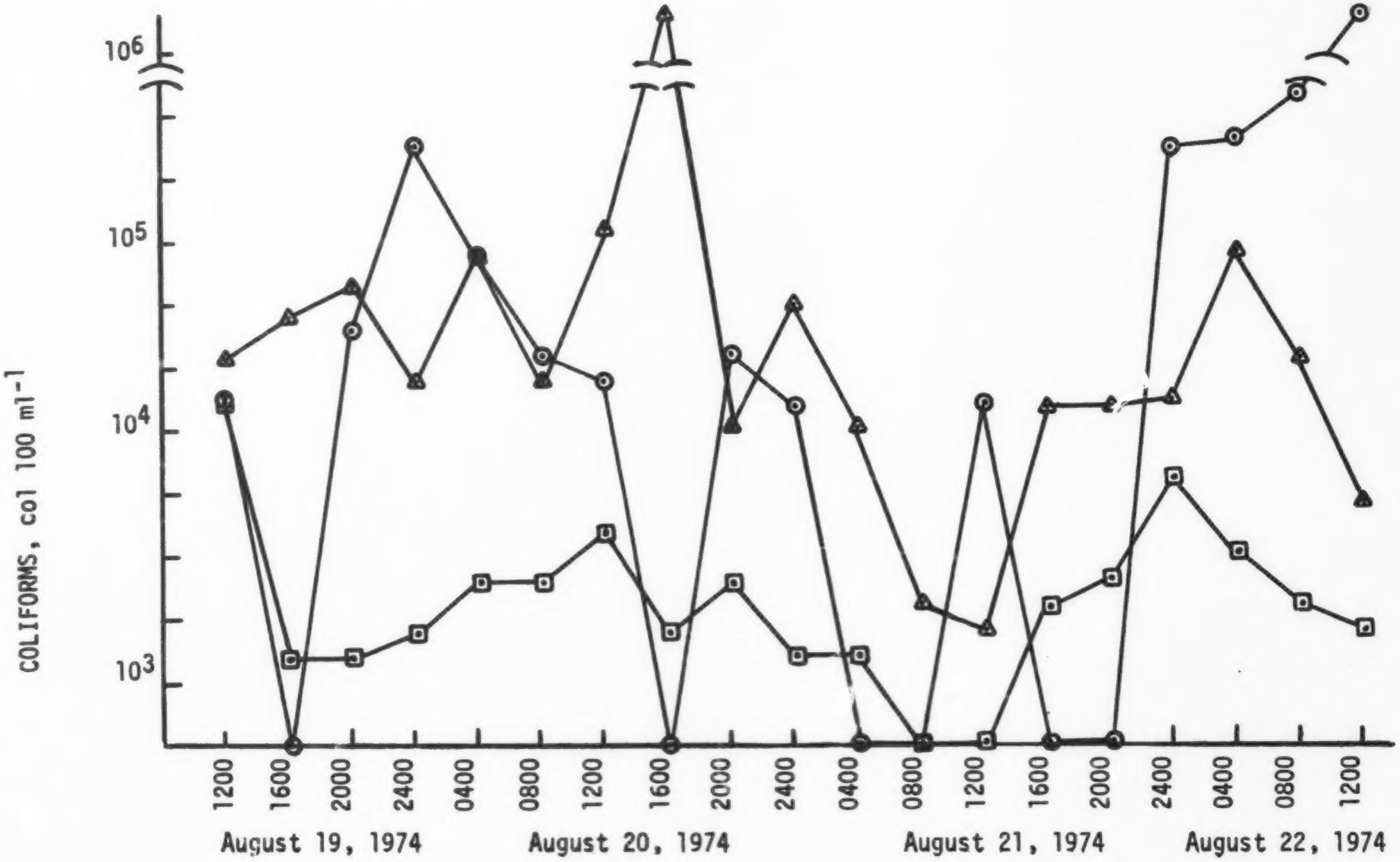


Figure F-8. Short Term Variation in Coliform Levels in the Brillion Marsh Study.
(△ - Station I; ⊙ - Station II; ⊡ - Station III)

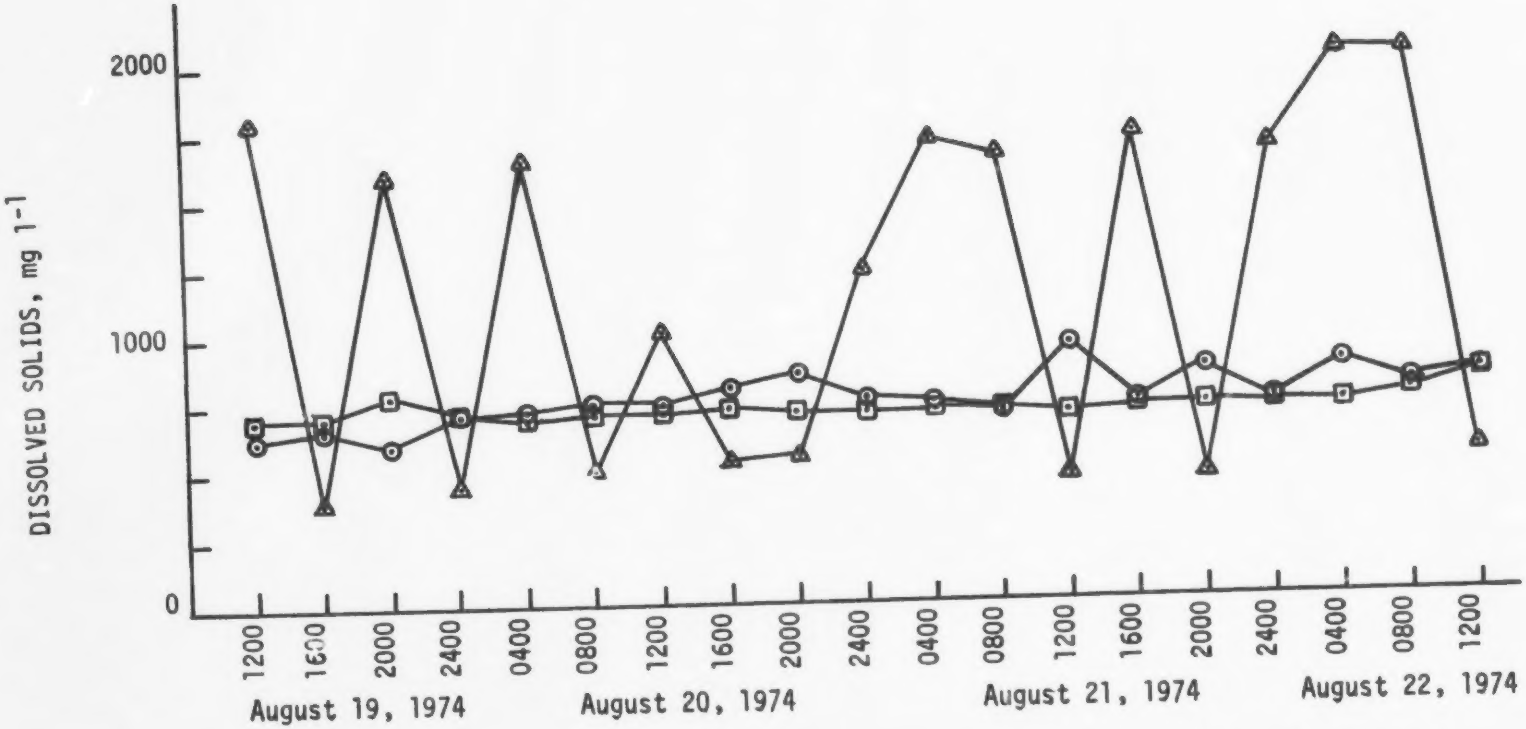


Figure F-9. Short Term Variation in Dissolved Solids Concentration in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ⊡ - Station III)

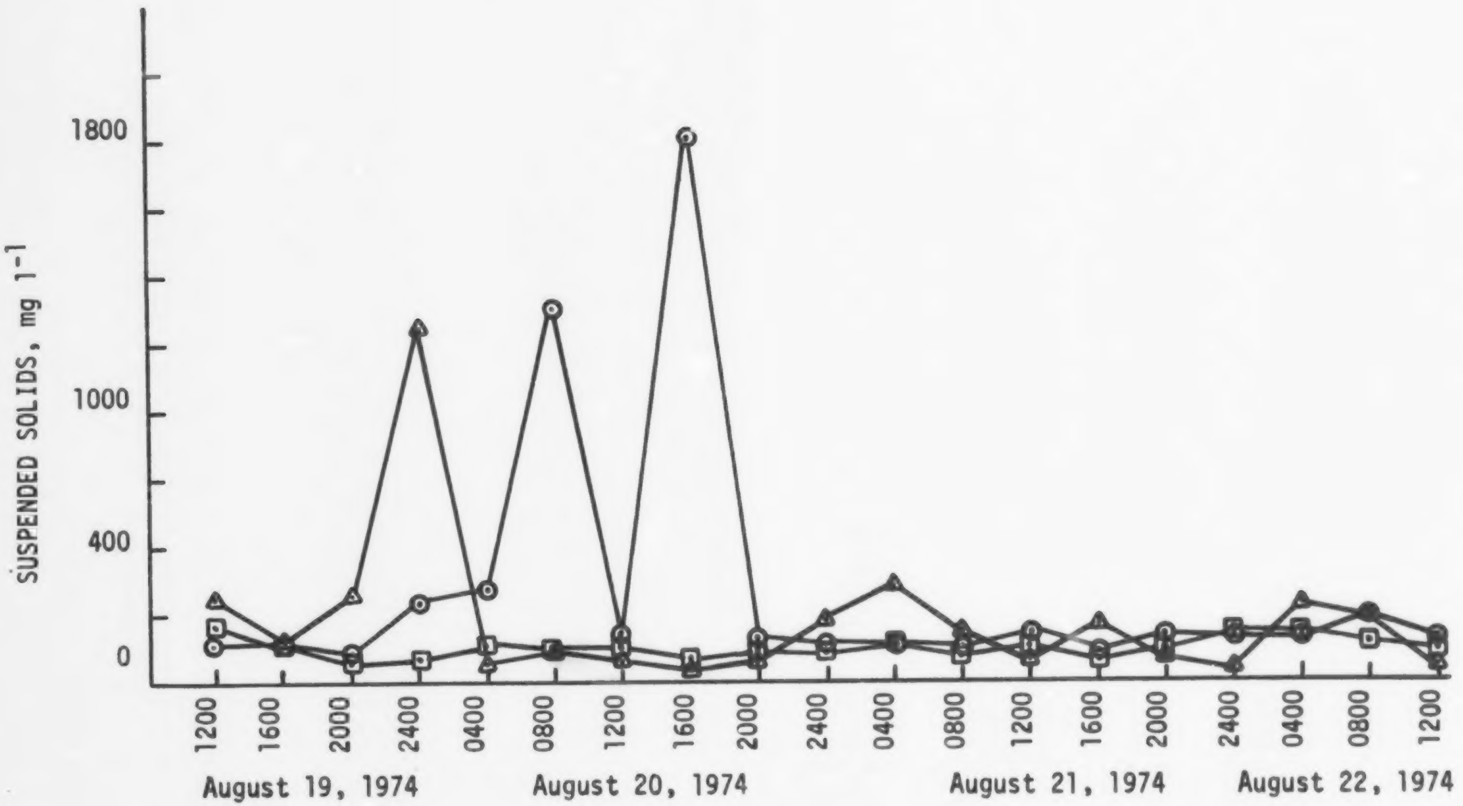


Figure F-10. Short Term Variation in Suspended Solids Concentration in the Brillion Marsh Study. (△ - Station I; ⊙ - Station II; ⊡ - Station III)

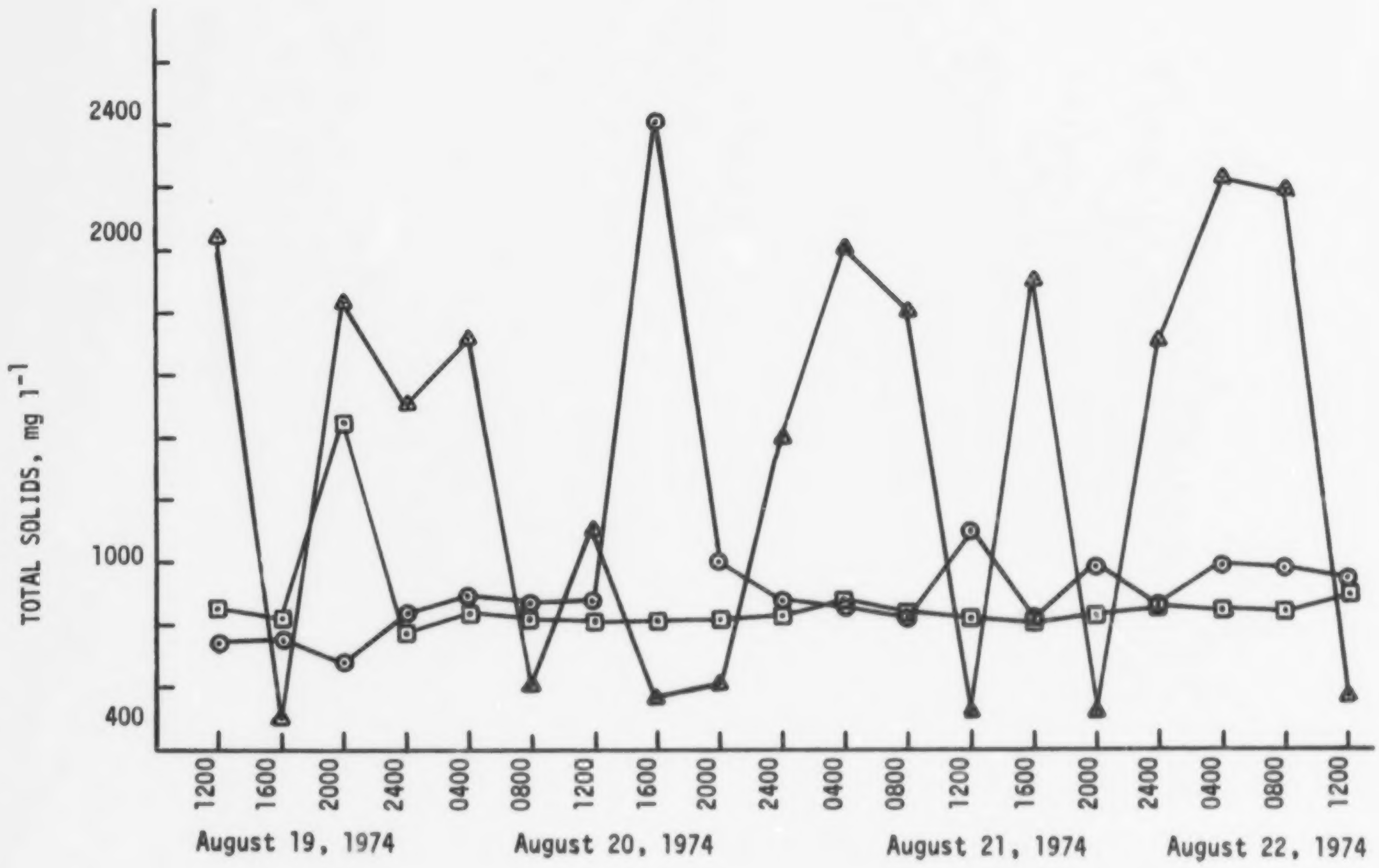


Figure F-11. Short term Variation in Total Solids Concentration in the Brillion Marsh Study. (△- Station I; ⊙ - Station II; ⊡- Station III)

Table F-1. CHEMICAL ANALYSIS OF SAMPLES[a] FROM STATION I LOCATED ON SPRING CREEK ABOVE THE BRILLION TREATMENT PLANT.

	BOD	COD	Total phosphorus	Ortho-phosphate	Conduc-tivity (umho)	Turbidity (JTU)	Nitrate	pH	Total solids	Suspended solids	Dissolved solids	Coliform (log col. 100 ml^{-1})
June 19, 1974	6.3	34	0.92	0.84		11		7.70				
July 1	14.9	57	1.08	1.23	800	8		8.80				4.40
July 9	4.0	4	0.76	0.64	500	5		8.00				4.63
Aug. 1	3.6	25	0.11	0.80	1750	5		7.78				5.43
Sept. 11	14.2	36	0.27	0.27	3100	9		7.96				4.45
Sept. 28	7.1	62	0.26	0.36	2700	9		8.00				3.04
Oct. 8	6.7	21	1.14	1.31	850	8	1.03	8.08				3.18
Oct. 29	11.5	34	2.26	1.78	1750	21	1.23	7.64				
Nov. 20	5.5	24	3.61	2.92	3000	5	2.20	8.21				3.80
Nov. 21	3.5	0	1.61	1.46	760	7	2.44	8.01				3.65
Dec. 17	5.9	0	0.08	0.08	2970	5		8.06				4.45
Feb. 11, 1975	7.2	9	0.03		950	6		7.13				
Mar. 4	5.1	4	0.05	0.02	775	6		7.90				2.78
Apr. 22	4.8	25	0.11	0.07	1000	7	1.54	7.00				
June 5	6.7	21	0.78	0.66	800	16		8.20	567	93	474	
June 12	4.9	44	0.38	0.40	1800	13	0.84	7.70	1080	214	866	4.75
June 19	4.7	47	0.38	0.32	750	9	4.25	7.85	782	80	702	4.40
June 26	2.2	34	0.16	0.16	2900	5	0.94	8.24	570	87	483	4.85
July 1	2.5	4	0.19	0.12	750	6	1.55	8.25	515	20	495	5.49
July 17	3.8	14	0.25	0.17	1800	6	1.24	7.85	1163	14	1149	4.42
July 29	2.2	22	12.76	12.98	1725	5	0.95	7.95	1209	1	1208	4.00
Aug. 5	2.7	35	1.03	0.07	2150	5	1.55	8.10	1409	12	1397	3.19
Aug. 28		147			282	420	3.40	7.50	1303	869	434	

[a] All values are expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table F-2. CHEMICAL ANALYSIS OF SAMPLES[a] FROM STATION II LOCATED ON SPRING CREEK BELOW THE BRILLION SEWAGE TREATMENT PLANT.

	BOD	COD	Total phosphorus	Ortho-phosphate	Conductivity (umho)	Turbidity (JTU)	Nitrate	pH	Total solids	Suspended solids	Dissolved solids	Coliform (log col. 100 ml-1)
June 19, 1974	7.2	30.4	0.79	0.65		15		8.00				
July 1	9.8	52.5	2.29	1.97	850	15		8.75				5.20
July 9	2.8	15.7	1.56	0.82	570	6		7.93				5.99
Aug. 1		49.3	3.68	3.39	900	16		7.73				4.80
Sept. 11	13.3	102.6	3.71	3.71	1450	15		8.01				5.80
Sept. 28	22.0	87.4	2.58	2.42	1450	16		7.76				4.80
Oct. 8	74.0	130.2	8.10	6.48	1000	30	0.48	7.70				3.48
Oct. 29	62.5	115.6	5.62	5.62	1850	37	0.41	7.46				
Nov. 20	100.0	64.6	8.20	6.95	1100	11	1.10	8.00				3.62
Nov. 21	51.5	137.3	6.27	5.51	1250	17	0.91	7.85				3.70
Dec. 17	23.0	79.2	2.54	2.28	1200	16		7.90				3.84
Feb. 11, 1975	18.3	45.4	1.06	0.90	1100	9		7.65				
Mar. 4	39.5	90.2		3.95	1160	20		7.90				
Apr. 22	11.7	34.8	1.60	0.80	725	9	1.20	7.90				
June 5	13.0	23.0	2.90	2.73	775	20		7.85	815	249	566	
June 12	25.0	64.0	3.45	3.24	825	37	1.19	7.55	601	119	402	6.07
June 19	9.2	48.2	0.81	0.60	700	12	5.30	7.80	638	36	602	4.34
June 26	15.8	41.8	3.51	3.41	1320	10	0.56	8.12	628	87	541	6.02
July 1	15.3	17.3	3.23	2.98	650	12	1.40	7.65	706	138	568	5.90
July 17	7.0	11.9	0.60	0.53	1700	7	0.40	7.75	1022	90	932	4.36
July 29		61.4	10.27	10.46	1325	14	0.25	7.65	805	76	730	5.81
Aug. 5	38.5	64.0	2.13	2.04	1200	13	0.18	7.60	807	126	681	4.93
Aug. 28	20.5	71.3	1.13	0.17	319	12	1.80	7.25	341	140	201	5.23

[a] All values are expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table F-3. CHEMICAL ANALYSIS OF SAMPLES[a] FROM STATION III LOCATED ON THE OPEN CHANNEL BELOW THE UPPER PORTION OF BRILLION MARSH.

	BOD	COD	Total phosphorus	Ortho-phosphate	Conduc-tivity (umho)	Turbidity (JTU)	Nitrate	pH	Total solids	Suspended solids	Dissolved solids	Coliform (log col. 100 ml^{-1})
June 19, 1974	4.2	52.5	1.15	0.94		4		7.90				
July 1	2.7	52.5	2.20	1.93	500	4		8.50				4.08
July 9	4.3	66.6	2.95	2.42	600	3		7.49				4.04
Aug. 1	5.0	76.8	0.97	0.88	825	5		7.76				3.49
Sept. 11	4.9	34.0	0.48	0.47	1500	5		8.30				3.00
Sept. 28	2.9	31.7	0.42	0.47	1310	5		7.96				4.26
Oct. 8	2.5	47.6	1.80	1.16	1600	6	0.48					2.00
Oct. 29	3.7	40.4	1.25	1.25	1500	5	0.54	7.85				
Nov. 20	2.3	32.1	1.83	1.53	1325	2	1.04	8.01				3.00
Nov. 21	2.6	48.6	1.02	1.04	1375	2	1.25	8.10				3.04
Dec. 17	4.0	93.4	1.67	1.98	1525	7	1.04	7.70				3.15
Feb. 11, 1975		61.5	3.88	3.60	1125	26		7.20				
Mar. 4	29.0	13.7	4.90	4.30	1600	12		7.00				
Apr. 22	8.7	40.4	0.42	0.32	640	5		8.00				
June 5	1.7	72.0	2.56	2.94	850	4		7.85	597	47	550	
June 12	3.8	61.4	1.95	2.34	800	40	0.46	7.50	550	90	459	4.10
June 19	1.3	70.3	2.01	1.91	825	14	0.03	7.25	759	87	672	3.84
June 26	5.6	92.2	7.33	9.10	890	23	0.41	7.88	518	46	472	4.74
July 1	7.1	53.4	11.85	10.27	775	30	1.70	7.60	957	121	836	5.35
July 17	6.7	118.8	2.43	2.33	825	4	0.04	7.25	1072	15	1056	4.68
July 29		102.8	10.52	10.85	825	16	0.15	8.00	972	7	964	4.70
Aug. 5	8.4	102.8	1.56	1.67	875	24	0.01	7.65	820	29	791	4.95
Aug. 28	4.3	47.5	0.43	0.79	610	7	0.45	7.45	659	365	294	5.44

[a] All values are expressed as mg l^{-1} unless otherwise indicated in parentheses.

Table F-4. CHEMICAL ANALYSIS OF SAMPLES[a] FROM THE OUTFLOW PIPE OF THE BRILLION SEWAGE TREATMENT PLANT.

	BOD	COD	Total phosphorus	Ortho-phosphate	Conduc-tivity (umho)	Turbidity (JTU)	Nitrate	pH	Total solids	Suspended solids	Dissolved solids	Coliform (log col. 100 ml-1)
July 9, 1974	55	133	9.82	9.31	950	39		7.54				
Sept. 11	82	173	7.23	7.23	1000	35		7.78				
Sept. 28	137	284	10.11	9.50	940	52		7.48				3.60
Oct. 8	170	309	12.08	9.91	1130	58	0.66	7.60				
Oct. 29	128	291	8.29	8.29	1100	53	0.61	7.60				5.20
Nov. 20	112	234	15.84	13.50	1100		0.48					3.90
Nov. 21	81	149	8.76	8.21	1100	21	0.44	8.01				3.47
Feb. 11, 1975	132	317	12.86	8.80	1100	62		7.60				
Mar. 4	112	293			1100	54		7.50				3.70
Apr. 22	61	175	6.19	5.35	1025	46	0.46	7.35				
June 5	36	97	13.04	10.78	800	24		7.50	641	75	566	
June 19	19	115	8.01	6.68	800	28	0.40	7.65	784	33	751	3.00
June 26	47	137	8.78	7.03	990	28	0.30	8.02	484	45	439	2.30
July 1	58	157	12.41	12.47	900	40	1.00	7.60	611	72	539	2.00
July 17	70	184	10.82	9.29	1425	38	0.09	7.30	623	30	593	4.11
July 29		234	1.26	1.03	1075	41	0.10	7.60	710	69	642	3.43
Aug. 5		262	7.40	6.00	975	62	0.20	7.60	769	36	733	4.34
Aug. 28	27	57	1.23	0.96	242	76	1.90	7.15	469	12	457	6.14

[a]All values are expressed as mg l^{-1} unless indicated otherwise in parentheses.